California Energy Commission

Bird Strike Indicator/Bird Activity Monitor and Field Assessment of Avian Fatalities

Consultant Report

PUBLIC INTEREST ENERGY RESEARCH

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Bird Strike Indicator/Bird Activity Monitor and Field Assessment of Avian Fatalities

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Interim Report, October 2003

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REPORT SUMMARY

Utilities, regulatory agencies, and environmental organizations are increasingly concerned about avian interactions with overhead power lines, communication towers, wind turbines, and other utility structures. Collisions and electrocutions kill birds and cause outages, but a lack of automated monitoring methods makes it impossible to quantify the problem or to evaluate possible mitigating measures. This interim report describes results to date of a project to develop automated monitors to gather information on bird strikes and evaluate the efficacy of mitigating devices such as line markers and flight diverters.

Results & Findings

Two different types of monitor are needed: a Bird Strike Indicator (BSI) and a Bird Activity Monitor (BAM). BSI is an impulse-based vibration sensing and recording tool to study bird collisions with aerial cables. BAM is an intelligent image-based sensing and recording tool to assist with detailed study of wildlife interactions with various types of structures. A Pre-Prototype BSI system, based on an earlier system developed by Pacific Gas & Electric, is complete; and its functional specifications are included in the report. The BAM is at an earlier stage of development.

To prepare for field testing of the new equipment and to develop an experimental design for testing the efficacy of mitigating measures, the BSI Project conducted dead bird surveys for two years at a North Dakota study site.

On-site testing of the BSI and BAM will take place at a transmission line segment that parallels U.S. Highway 83 between Lake Audubon and Lake Sakakawea in central North Dakota. This line segment has a history of bird collision problem; during one 3-month period in 1976 a total of 244 birds were found. The line segment is located on the western boundary of Audubon National Wildlife Refuge. Once fully evaluated, the BSI and BAM may provide cost effective alternatives to ground searches. After initial testing of BSI prototypes during the third year of baseline dead bird surveys, wires in a subset of spans at the study site will be marked to mitigate collisions.

Challenges & Objectives

Two primary goals of this project are to develop automated monitors to gather information on bird interactions that is difficult or impossible to obtain through direct human observation and to evaluate the efficacy of mitigating devices such as line markers and flight diverters.

Applications, Values & Use

New approaches to reducing interactions between birds and transmission and distribution structures, wind turbines, and communication towers can avoid outages, reduce costs, and enhance compliance with environmental regulations.

EPRI Perspective

EPRI has conducted two workshops on avian interactions with utility structures (EPRI reports TR-103268 and 1005180).

Approach

The project team began development of a prototype bird strike indicator with state of the art electronics and prepared to test the system in the laboratory and in actual field settings. The team initiated development of a bird activity monitor, and conducted dead bird surveys to document annual numbers and spatial distribution of avian fatalities at the North Dakota study site.

Keywords

Birds
Bird strike indicator (BSI)
Bird activity monitor (BAM)
Power lines
Overhead structures

ABSTRACT

Bird collisions associated with overhead power lines and other structures are a concern for utilities. While techniques for assessing the issue have been available since the early 1980s, quantifying the problem and assessing possible mitigation approaches has been difficult, in part because of a lack of standard monitoring methods. This interim report describes results to date of a project to develop automated monitors to gather information on bird strikes and evaluate the efficacy of mitigating devices such as line markers and flight diverters. Two different types of monitor are under development: a Bird Strike Indicator (BSI) and a Bird Activity Monitor (BAM).

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1 INTRODUCTION

Avian interactions (i.e. collisions and electrocutions) with overhead power lines, communication towers, wind turbines, and other utility structures are subjects of increasing concern among utilities, regulatory agencies, and environmental organizations. Heightened awareness of the problem has led to greater efforts (sometimes misguided) to mitigate and reduce avian fatalities and to increase power reliability. However, our ability to quantify the temporal and spatial extent of the problem or the efficacy of mitigating measures is severely hampered by a lack of standard monitoring methods. To bridge this technology gap, EPRI, The California Energy Commission's Public Interest Energy Research-Environmental Area (CEC PIER-EA), Western Area Power Authority (Western) and other utilities propose to develop and deploy automated avian monitors that can be cost-effectively used in remote locations to capture vital information necessary to develop programs to minimize impacts of utility structures on bird populations. This project is consistent with the mission of the CEC PIER-EA program to develop cost-effective approaches to evaluating and resolving environmental effects of energy production, delivery and use in California and explore how new electricity applications and products can solve environmental problems.

Two primary goals of this project are 1) to develop automated monitors to gather information that is difficult or impossible to obtain through direct human observation, and 2) to evaluate the efficacy of mitigating devices such as line markers and flight diverters. Additionally, this project supports the PIER Program objectives of 1) Reducing the cost of energy and improving the value of California's electricity by increasing power reliability and reducing outages caused by avian interactions with utility structures, and 2) Improving the environment and mitigating risks of California's electricity by evaluating the efficacy of devices to reduce avian fatalities.

Two different types of monitor are needed: a Bird Strike Indicator (BSI) and a Bird Activity Monitor (BAM). BSI is an impulse-based vibration sensing and recording tool to study bird collisions with aerial cables. BAM is an intelligent image-based sensing and recording tool to assist with detailed study of wildlife interactions with various types of structures. The basic concept for the two devices is illustrated in Figure 1-1. Other situations that could be monitored with the BAM include flight activity near proposed or existing wind turbine sites or communication towers, wildlife activity in/near substations, perching or nesting activity on towers, and the efficacy of mitigating measures. Many other opportunities exist for using BAM as a general-purpose wildlife monitoring tool for studying and mitigating wildlife damage problems.

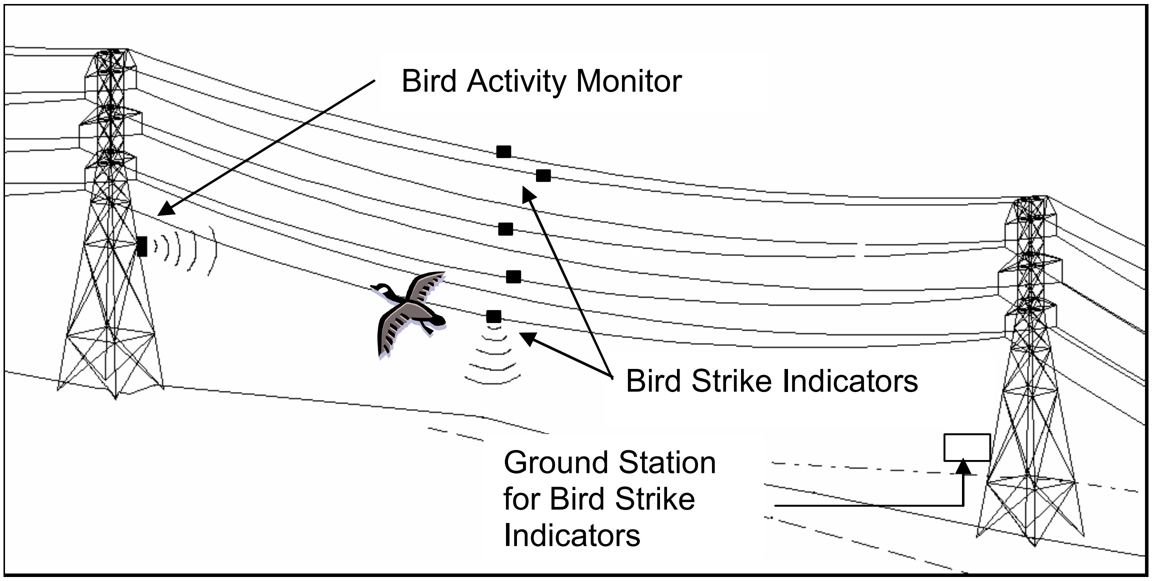

Figure 1-1
Possible Attachment Locations for Bird Activity Monitor and Bird Strike Indicators and their Associated Ground Station

On-site testing of the BSI and BAM will take place at a transmission line segment that parallels U.S. Highway 83 between Lake Audubon and Lake Sakakawea in central North Dakota. This line segment has a history of bird collision problems and during one 3-month period in 1976 a total of 244 birds were found (McKenna and Allard 1976). The line segment is located on the western boundary of Audubon National Wildlife Refuge, managed by the United States Fish and Wildlife Service (USFWS), and the Refuge is participating in the study. Once fully evaluated, the BSI and BAM may provide cost effective alternatives to ground searches. Meanwhile we depend on dead bird searches for primary data in this study. After initial testing of BSI prototypes during the third year of baseline dead bird surveys, wires in a subset of spans at the study site will be marked to mitigate collisions. Although numerous devices are available to make wires more visible, little is known about their effectiveness. As development, deployment, and evaluation of BSI and BAM systems continue during the marking experiment, data from these instruments will supplement dead bird survey data and may provide an independent data set for evaluating wire-marking efficacy.

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BIRD STRIKE INDICATOR

The BSI is an impulse-based vibration sensing and recording tool to study bird collisions or "strikes" on wires. The basic premise is that a collision will result in vibration being induced into the wires that can be monitored and detected. The challenge is to develop a device that can reliably detect strike induced vibrations in the presence of other noises like wind induced vibration. The goal for this project is to take an existing PG&E prototype, update/redesign it with state of the art electronics and test/refine the system in the laboratory and actual field settings. The system will be validated in the field with bird searches.

Background

The Bonneville Power Administration's (BPA) Division of Laboratories was the first to develop an experimental bird/power line collision detection system during the 1980s. The system consisted of a horizontal plane accelerometer clamped to the overhead ground wire and electronics for signal conditioning and capture. The signals from the accelerometer were transmitted using fiber optic cables to the tower base and then regular cables were used to connect it to a four-channel vibration recorder. The main problem with this system was that the direct connection using cables resulted in shorts causing outages. The vibration recorder was an analog system that recorded vibration data as sounds on magnetic tape that needed to be digitized and processed. The recorder could only record up to 8 hours continuously. The system produced a lot of spurious signals that made it difficult to distinguish bird collisions from other source of natural vibrations.

Pacific Gas and Electric's (PG&E) Research and Development (R&D) Department directed development of a prototype bird/power line collision detection system during the 1990s. The system used a modified Nitech Power Donut originally developed by Nitech, Inc. The system consists of a self-contained sensor unit with a horizontal plane accelerometer that is mounted on the power line. The sensor monitors vibration and transmits a digitized signature of any impacts, along with the date, time of day, and conductor temperature to a ground station, where it is stored for later retrieval. The early prototypes were expensive ($25,000 per sensor), bulky, heavy, and could not be used on lines less than 115 kV. In the late 1990s CEC PIER-EA supported PG&E research to modify the Power Donut with custom electronics consisting of Analog-to-Digital converter, radios and a battery pack. Figure 2-1 shows the prototype developed by PG&E.

Controlled testing of this redesign revealed that the new prototype did not provide reliable data due to problems associated with transmitting data to the ground station. PG&E has no plans to resume development of the BSI. However, they are willing to support further development of the BSI. The PG&E prototype needs to be redesigned as most of the electronics are outdated now.

EDM obtained a prototype BSI and technical documentation from PG&E. This information was used in development of the current prototype.

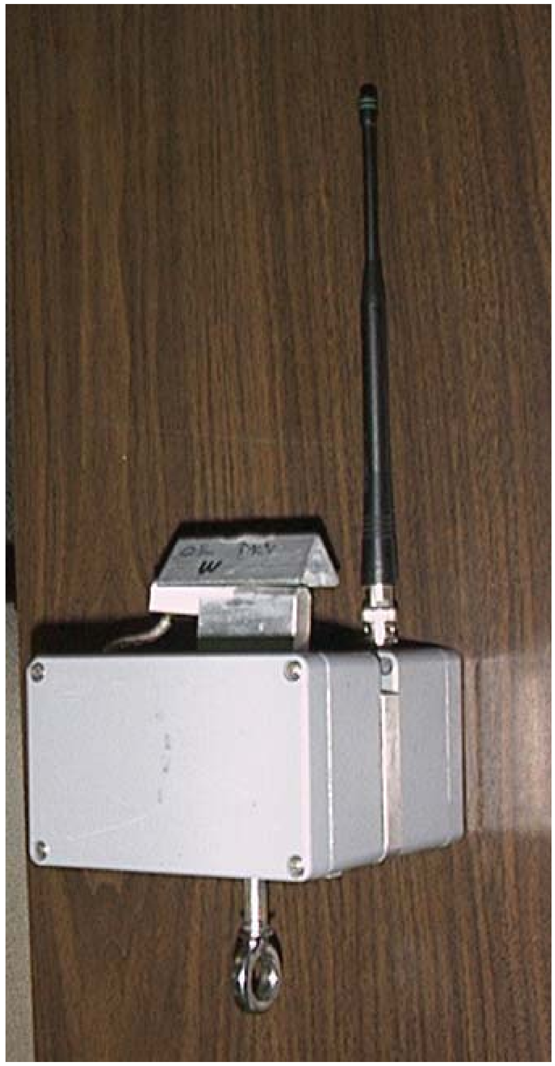

Figure 2-1
PG&E Prototype Bird Strike Indicator

BSI Prototype Development

A Pre-Prototype BSI system is under development from information collected from PG&E. All the components for the pre-prototype BSI sensor have been selected and the fabrication of a pre-prototype BSI is complete except for the firmware. Firmware for the BSI sensor is currently under development and is scheduled for completion in early 2003.

Functional specifications for the prototype BSI are provided in Appendix A. The BSI sensor consists of state-of-the-art accelerometers, clamps, power supplies, signal processors, and data acquisition systems. These newer components have been assembled and configured to provide the basic sensing capabilities of PG&E's existing prototype BSI. The BSI Pre-Prototype system includes a sensor system for real-time monitoring of avian collisions (including the appropriate firmware still under development), a power supply for the sensor, and a communication system for transmitting data to a ground-based unit in which raw data are stored.

The sensor system includes appropriate signal processing and data logging capabilities. Operating parameters for the sensor will be developed for a range of line configurations (e.g. distribution and transmission size conductors) during the laboratory testing. Sensitivity will also be evaluated to maximize the range of detectable bird sizes and to minimize false strike triggers.

BSI Sensor Hardware

A complete BSI system consists of BSI sensors that will be mounted on the wire to be monitored and a base station that will gather strike data from several sensors and provide remote access to the data using a variety of communication options. The BSI sensor integrates several components to provide the needed functionality for monitoring and recording bird strikes. A picture of the prototype BSI sensor and its components is shown in Figure 2-2. The BSI sensor consists of the following major components:

1. Accelerometer
2. BSI Circuit Board
   - Analog Filters
   - Microcontroller with A/D
   - Data Storage
3. Wireless Radio
4. Power Supply
5. Mounting Clamp and Enclosure

Accelerometer

The BSI has been designed such that a variety of accelerometers can be used with it. The key to selecting an accelerometer for the BSI is its size, frequency response and power consumption. The following two accelerometers, shown in Figure 2-3, have been identified to work with the BSI:

1. Crossbow HF Series Tri-axial accelerometer
2. Endevco piezoPAK Model 55L

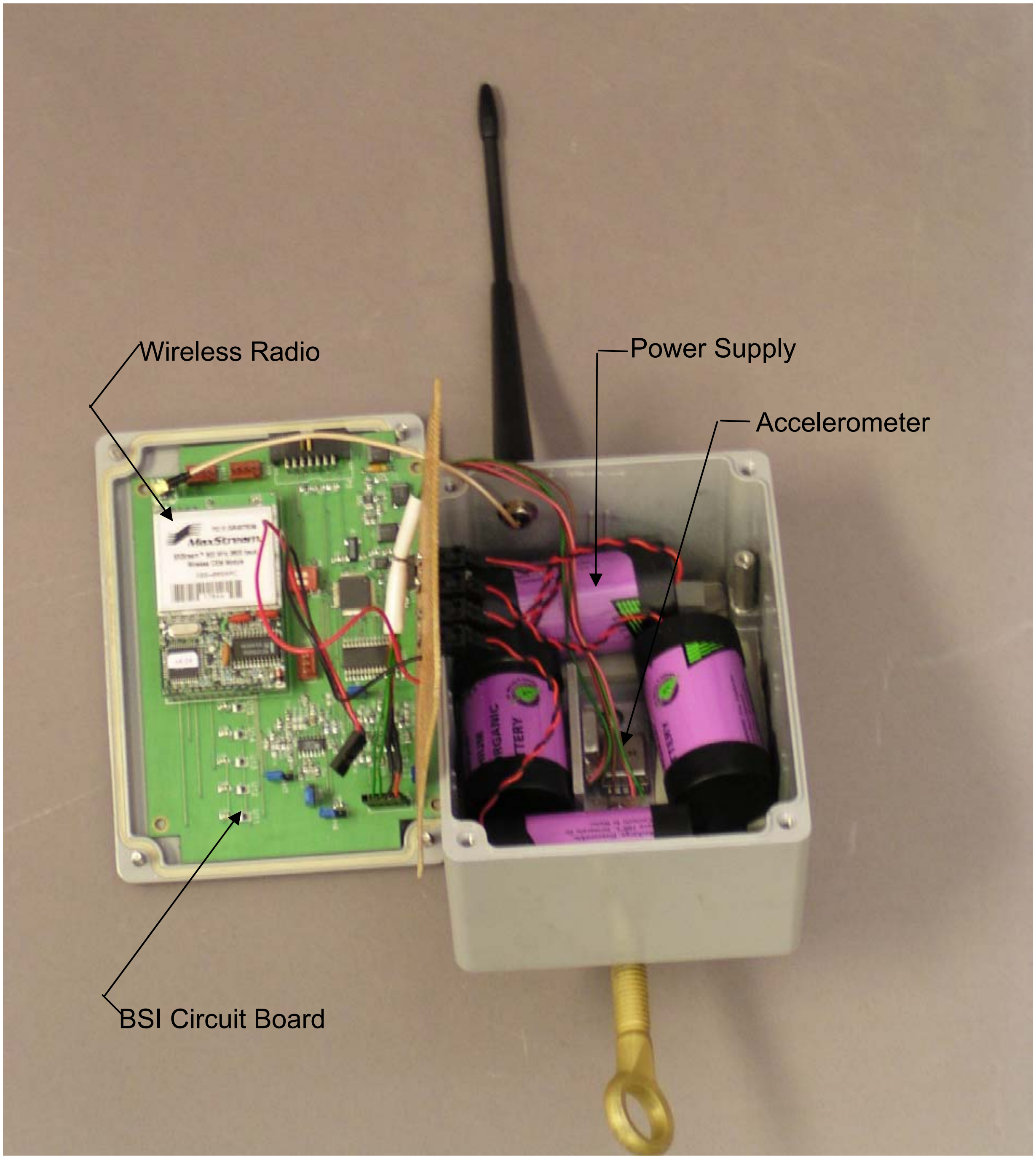

Figure 2-2
Prototype BSI Sensor Components

Endevco piezoPAK

Figure 2-3
Accelerometers Selected for BSI

The Crossbow accelerometer is a tri-axial accelerometer of which two-axes perpendicular to the axis of the wire will be used. The Endevco piezoPAK is a single-axis accelerometer and two of these accelerometers will be used with the BSI. The key difference between the two is in the power consumption. Two of the Endevco accelerometers consume approximately one-tenth power compared to the Crossbow tri-axial accelerometer. Power consumption of the accelerometer is the key to extending the battery life as the accelerometer will be the one item that will consume power all the time as it needs to continuously remain on. The use of the Endevco accelerometer will considerably reduce the power consumption of the BSI. However, the Crossbow accelerometer appears to have a more rugged packaging. Table 2-1 provides a comparison of specifications for the two accelerometers.

Table 2-1
Comparison of Specifications for the Two Accelerometers

Specification	Crossbow	Endevco
Input Range (g)	10 or 100	10 (up to 25) or 100
Sensitivity (mV/g)	100 0r 10	100 or 10
Bandwidth (Hz)	0.3 – 10,000	2 – 10,000
Operating Temperature (^{o}C)	-40 to 125	-40 to 125
Shock Limit (g)	5000	5000
Supply Voltage (Vdc)	5 – 30	2.7 – 5.5
Supply Current (mA)	1	0.04 (0.08 for 2)

The accelerometer is mounted to the bottom of the BSI enclosure in the center which in turn gets mounted to the clamp. Mounting the accelerometer inside the enclosure should not affect the performance as we are measuring only low frequency vibration.

BSI Circuit Board

The core of the BSI circuit board, shown in Figure 2-4, is the Texas Instruments MSP430F149 micro controller (μC). This ultra-low-power 16-bit controller includes an integrated 12-bit analog to digital (A/D) converter, 60 KB of flash memory, and 2 KB of ram memory. The μC handles digitization and recording of the accelerometer waveform, communications with the base station through an integrated universal asynchronous receiver/transmitter (UART), and time-based event handling such as reporting the sensor's status at programmed intervals. The firmware which controls the sensors operation is stored in the flash memory. Thus, when power is applied to the sensor printed circuit board, the μC runs through an initialization routine and then goes into operation. Part of the startup is initialization of the A/D registers. These registers control the sample rate, gain, and sequence of digitization. Besides the two accelerometer channels, the A/D can read the sensor battery voltage and the temperature of the μC (which due to its low power consumption is practically the temperature of the sensor enclosure). In addition to the μC, the BSI circuit board includes two crystal oscillators which provide a real-time clock function and a stable digitizing clock, an external memory for waveform storage, a power conversion and management circuit, level shifters for the serial link, and two analog filter banks for the accelerometer channels.

Figure 2-4
Prototype BSI Sensor Circuit Board

Since the amount of ram memory within the µC is limited, a 32KB static ram (SRAM) was added to the circuit board for waveform storage. The µC is continuously digitizing the two channels of accelerometer data while looking for signals which cross a programmed threshold level. When the threshold is crossed, the µC marks a portion of the data it has already digitized (pre-data) for keeping, proceeds to digitize a programmed amount of data after the threshold crossing event (post-data), and then sets these data aside and starts a new buffer. The "strike" data is then held in SRAM until it can be sent to the base station.

Each analog input from the accelerometer is conditioned by a pair of analog filters connected in series. In the present device, the first filter is configured as a 2 Hz high pass filter and the second as a 60 Hz notch filter. The high pass is used to eliminate 1/f noise and the notch is used to reduce the 60 Hz power-line current induced vibration which is expected to be a significant source of interference. These filters can be modified by substituting different values for the resistor/capacitor networks. Thus, as line testing proceeds, the filter responses can be varied to tailor the BSI sensors to the actual operating environment without redesigning the printed circuit boards. The performance of the analog filters is illustrated in Figure 2-5.

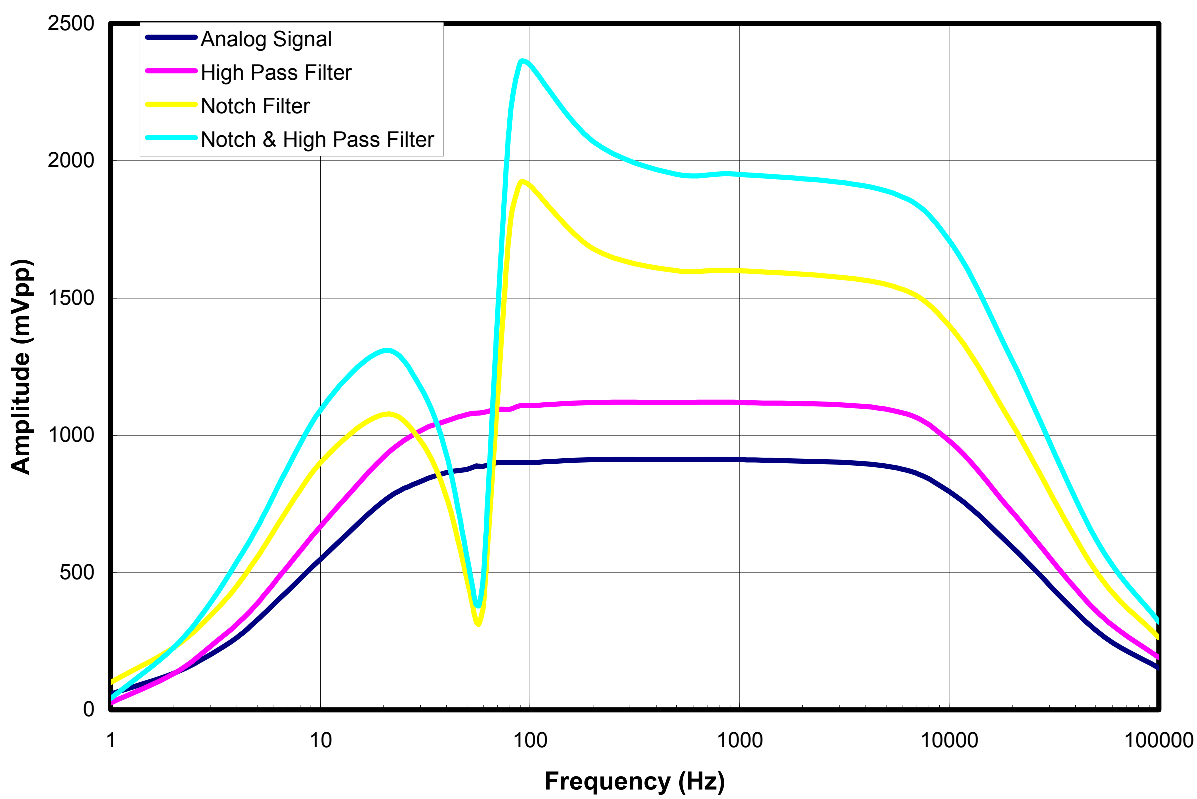

Figure 2-5
Analog Filter Frequency Response

Wireless Radio

The BSI sensor and the BSI base station communicate with each other through a RS232 serial link (driven by the on-chip UART) and a set of 900 MHz wireless radio modems. The selected wireless radio modem in the BSI sensor plugs directly into the BSI circuit board. The wireless modem operates in the 902-928 MHz FCC approved unlicensed frequency band. The radio uses the frequency hopping spread spectrum technology where it switches from one frequency to another to avoid interference. The selected wireless radio will operate at 9600 bps and has a transmit power output of 100 mW. The range for these radios is greater than one mile with a dipole antenna. The radios will be kept either in powered down state or in a cyclic power down mode except when the sensor needs to communicate with the base station to conserve power supply.

Power Supply

Four D-size primary lithium batteries in parallel will be used to power the BSI. Each battery has a capacity of 16.5 Ah at 3.6 V providing a total of 66 Ah. The BSI circuit board includes the necessary power conversion and management circuit to provide 5 volts needed for several components. The battery capacity is designed to provide at least six-months of operation time for the sensors.

Packaging

The BSI electronics will be housed inside a weatherproof enclosure that will be mounted to an Utilco hot-line clamp (see Figure 2-6). These clamps are designed to be mounted to live conductors using a hot stick. Different size clamp will need to be used depending on the conductor size.

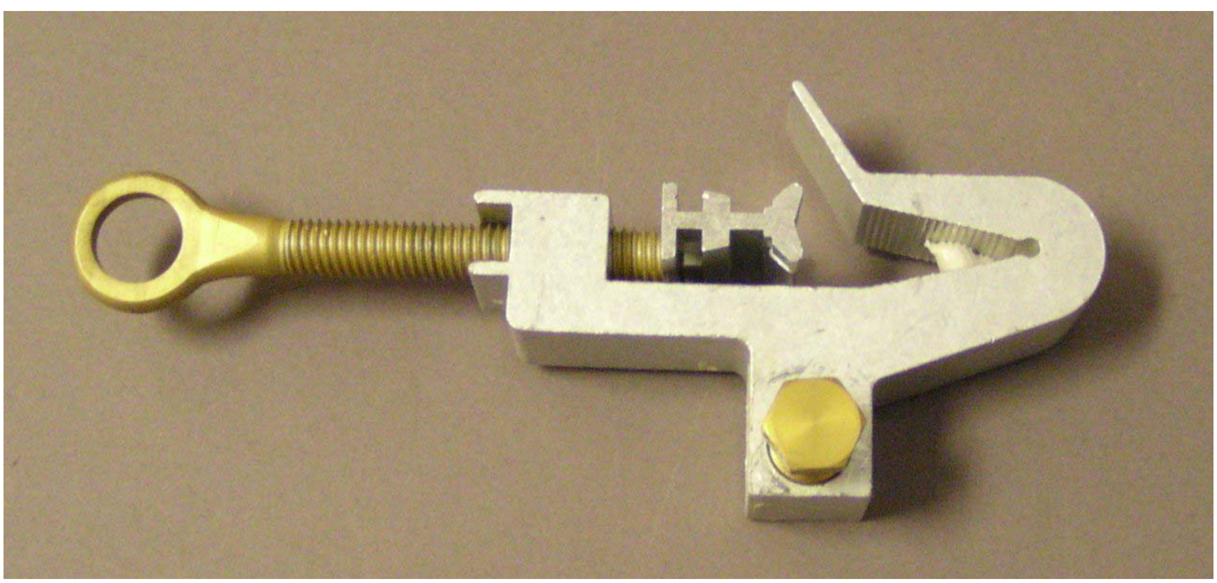

Figure 2-6
Typical Utilco Clamp Selected for Mounting BSI

The Utilco clamp is modified to create a flat surface to mount the weather-proof enclosure. The enclosure is approximately 4 inch wide by 5.5 inch long by 3 inch deep. A completely assembled BSI sensor along with the wireless radio antenna is shown in Figure 2-7.

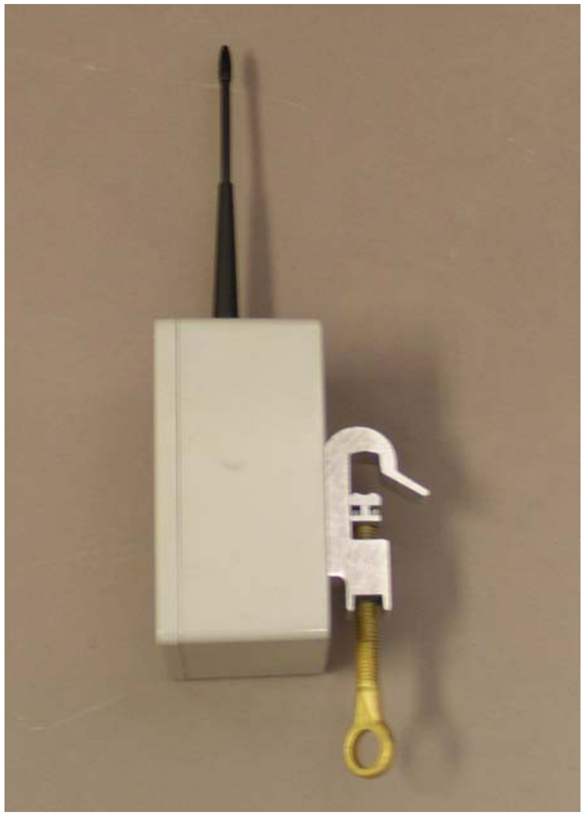

Figure 2-7
Prototype BSI Enclosure Mounted to the Utilco Clamp

Base Station

The base station consists of either a desktop computer or a self-contained “PC-in-a-Brick” computer depending on the site requirements. For sites where AC power is available and it is feasible to house a desktop computer, use of a desktop computer for the base station will provide some added flexibility. For remote sites, where the base station needs to be located outdoors, a brick computer housed in a weather-proof enclosure along with other hardware will be used.

The brick computer, shown in Figure 2-8, consists of a 386 microprocessor with 1 MB RAM and 8 MB flash memory for storage. It has two serial ports and an Ethernet port allowing serial or internet communication. One of the serial ports on the computer is used to connect the wireless radio used to communicate with the BSI sensors. The other serial port connects to a modem allowing remote communication with the base station over a regular or cellular phone line. The Ethernet port can be used to connect the base station to a wired or wireless LAN.

Figure 2-8
A Self Contained Brick Computer

For remote sites, the brick computer will be housed inside a weather-proof electronics enclosure along with the wireless radio and other hardware for the chosen communication option. A picture of the electronics enclosure is shown in Figure 2-9. The electronics enclosure has connectors at the bottom for connecting power supply, antenna for communication and other needed cables.

Figure 2-9
Enclosure Housing Brick Computer and Other Hardware for Base Station

AC powered systems consist of a power supply box, shown in Figure 2-10, to which AC power is fed through a weather head. The power supply box consists of a circuit breaker, surge arrester, charger-regulator and a battery to provide back-up power supply in the event of loss of AC power. Solar powered systems consist of a battery box and solar panel array. The size and number of solar panels, and the battery capacity is selected based on the solar insolation available at the installation site. A solar power supply package is shown in Figure 2-11.

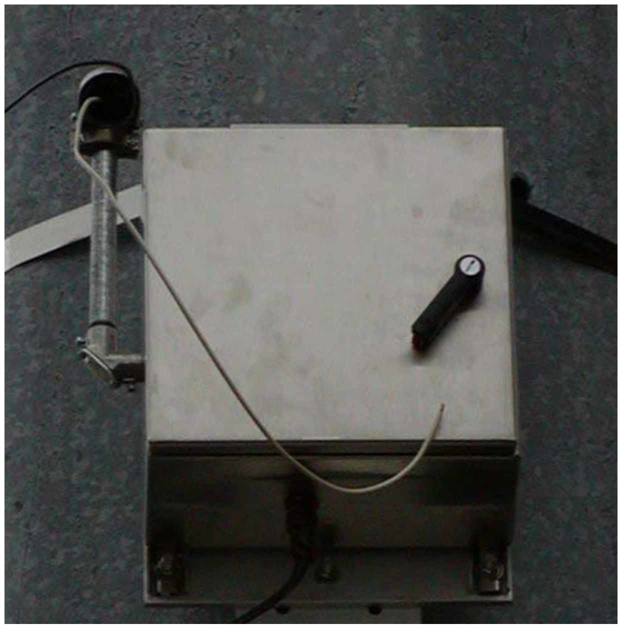

Figure 2-10
Power Supply Box for AC Powered Base Station

Figure 2-11
Solar Power Supply for the Base Station

BSI Operation

The BSI sensors are designed to operate on their own once powered up. The parameters controlling the operation of the BSI sensors are programmed into each unit. These parameters can be remotely changed by sending new parameters from the base station. There are several data acquisition parameters and operational parameters that can be configured. Data acquisition parameters include:

- ***Sampling rate*** controls the rate at which the analog signal is digitized and will be typically set at 1000 Hz.
- ***Threshold*** determines the level of vibration signal above which the vibration will be considered as a strike and the sensor will start recording strike data. Threshold will need to be determined from laboratory and field tests. This will be critical because a low threshold could result in several false strikes due to wind or other vibration signal. On the other hand, a high threshold will likely miss a few low impact strikes.
- ***Pre-Trigger and Total Number of Points*** determine the number of data points to be stored for each strike. Pre-trigger points control number points that are stored from before the threshold was reached. Total number of data points will typically be 1024 with approximately 100 pre-trigger data points resulting in a time record of one second duration.

The operational parameters for the BSI sensor include a unique sensor ID for each sensor, date and time. In addition a time and duration parameter is set at which all the sensors will be awake during the day, called WUTime and WUDuration, to receive communication from the base station. The WUTime and WUDuration for example could be midnight and 15 minutes. This is to allow the base station to change the parameters in all the sensors at once.

BSI Operation Modes

The BSI sensor can be in one of four operation modes at any given time. However, the sensor continues to monitor for strikes in all the different operation modes. The different operation modes are:

1. ***Normal Operation*** – Under normal operation, the sensor is monitoring acceleration from the two accelerometers to see if it has reached the threshold. All other systems are kept in either a low power state or turned off. For example, the wireless radio is either completely turned off or kept in a cyclic powered down state. The microcontroller keeps continuously monitoring for a trigger in the vibration signal exceeding the threshold. It always keeps digitizing and storing pre-trigger data in the buffer. Once a trigger state exceeding the set threshold is reached on any one of the two vibration channels, it continues digitizing until it has the total number of points for both axes and stores the strike data in on-board storage memory for communication to the base station. In addition to the strike data, it also stores the date and time of the strike along with the battery voltage and the internal temperature of the

BSI. Once a strike is detected the sensor begins initiating communication with the base station to report the strike.

2. ***Report Sensor Health*** – At a pre-determined time during the day based on the sensor ID, the BSI sensor initiates communication with the base station to report its health. The health report includes the current date, time, data acquisition parameters, operational parameters and the battery voltage. This data is logged at the base station for each sensor to be used to judge the condition of each BSI sensor. After successful reporting of the sensor health, the base station can send commands to the sensor to synchronize its clock or alter any of the sensor parameters.
3. ***Report Strike Data*** – Once a strike has been detected by the sensor, it initiates communication with the base station. If the base station is available, the sensor sends the stored strike data to the base station. The sensor first reports the general characteristics of the strike data including the date and time of the strike, sensor ID for determining location of the strike, the peak or RMS acceleration for the two-axes, battery voltage and the internal temperature. After this, the sensor sends the two axes digitized vibration data points one axis at a time.
4. ***Await Communication from Base Station*** – At a time determined by the sensor parameters, all the sensors keep their wireless radios powered up in anticipation of communication initiated from the base station. This mode is used to communicate with all the sensors at once by sending a unique ID reserved for this or to communicate with any one sensor. The base station can send new parameters to the sensors at this time, update their firmware or synchronize their clock. When the base station is communicating with multiple sensors at once, the sensors do not acknowledge the receipt of data. The sensors acknowledge receipt of data only if they are in communication with the base station alone.

Communication Protocol

A communication protocol has been developed to facilitate communication and to avoid bottlenecks. The protocol consists of the following basic rules:

- Before initiating communication, the sensors and base station will listen to see if other communication is ongoing,
- The sensors can communicate with the base station one at a time and only when the base station responds to their request, and
- If other communication is ongoing or the base station does not respond to their initial request, the sensors will wait a random amount of time before trying again. The purpose of using a random wait time between attempts to talk to the base station is to keep multiple sensors from trying to contact the base at one time.

The sensors initiate communication with the base station by sending a request which includes an address field and can continue communicating only if the base station acknowledges. A special address, for example 00 or 99, is reserved for the base station to address all sensors at once. This would be used to send a time sync command to all the sensors which are awake for instance. A sensor which has recorded a strike event will initiate a waveform transfer by querying the base station for its attention. If the base station is busy, it will not receive a response within an allotted amount of time and will go back to sleep for a random amount of time. Upon reawakening, it will try the base station again. When the base station responds, the transfer will be controlled by the base station, which will ask for the strike parameters and then each channel of data. The base station can then put the sensor back to sleep or send any other command.

Automatic/Remote Reset

To make sure the sensors do not get stuck in any unwanted state, a watchdog timer is included that monitors the microcontroller and automatically resets it. The base station also can send a command to reset the sensor if its radios are powered up.

Laboratory Testing of Pre-Prototype BSI

After completion of development of the BSI sensor firmware and the base station software, the pre-prototype BSI will undergo extensive laboratory and field testing to identify any refinements and optimization needed prior to full-scale field testing at the North Dakota test site. The laboratory evaluation is scheduled to begin in 2003.

The testing will consist of installing two BSI sensors on simulated test spans and simulating bird strikes by striking the wire. An instrumented impulse hammer will be used to generate simulated strikes. The instrumented hammer will allow for varying the intensity and frequency content of the strikes by varying the stiffness of the hammer tip. It will also let us monitor and record each of the simulated strikes to correlate it with the measured strikes from the BSI sensors. The location of the BSI sensors and the location of the strikes relative to the BSI sensors will be varied. This study will be used to develop the threshold to be used in the field testing.

The pre-prototype BSI design will be revised based on the results of the laboratory testing and the revised design will be used in the fabrication of the prototype BSI sensors. The results of this task will be reviewed with the Technical Advisory Group (TAG).

Field Testing of Prototype BSI

Field-testing will evaluate the functionality and survivability of the BSI system under actual operating conditions and identify needed design or operating refinements. Field testing is scheduled to start in 2004. Twenty functional prototype BSIs will be fabricated and calibrated in the laboratory for consistency between units. The units will then be deployed on selected problem spans at the Audubon National Wildlife Refuge. The project team will install the BSIs with assistance of the host utility's line crew. The project team will monitor the performance of prototype units for two-year study period.

3 BIRD ACTIVITY MONITOR

The Bird Activity Monitor (BAM) will capture, store, and transmit video images of the interaction of birds with power lines, communication lines, and towers when their flight paths approach facilities which have BAMs installed. This video information can then be used as a basis for objective investigation. The video information can be used in concert with ancillary measurements made by devices such as BSIs. BAMs can also efficiently monitor retrofitted lines to determine if mitigating measures are working.

The BAMs design will build on related technology that was developed for real-time monitoring of power line conductor ground clearance. The ground clearance monitor utilizes video technology coupled with sophisticated image processing software to accurately monitor and track the motion of conductors for thermal rating purposes. By leveraging the BAM R&D effort with the ground clearance monitoring technology, this project can proceed at a fast pace with lower cost and greater likelihood of success.

The following is a description of the project tasks for the development of BAM.

Task 1: Project Initiation and Administration (Completed in 2000)

The TAG for BAM has been assembled and has held a number of meetings and conference calls. A list of TAG members is provided in Appendix B.

Task 2: Develop Functional Specifications for System

EDM International, Inc. (EDM) will develop functional specifications for the system (e.g. sensor, signal processing, communication and deployment hardware) and firmware (e.g. data analysis, data management, system diagnostic, and communication firmware) to guide hardware and firmware-component design in subsequent tasks. Draft functional specifications will be distributed to the TAG for review and comment. The specifications will be refined as necessary based on the input received from the TAG.

Task 3: Develop Sensor Package Hardware and Firmware Design

EDM will develop the sensor package hardware and firmware design based on the functional specifications for the system. Designs will be developed for the sensor system for real-time monitoring, a power supply for the sensor and communication systems, and a communication system for transmitting data to a ground-based station.

The sensor system design will include activities to identify the appropriate optics, night vision or infrared illumination capabilities, motion detection features, signal processing capabilities, data logging capabilities, and optional ancillary measurements capabilities (e.g. measurements of ambient weather condition, and integration of measurements made by the bird strike monitor).

To accurately detect and record a bird strike, a trigger mechanism must be developed along with a pre-trigger recording mechanism. The project approach will be to use motion-sensing software to analyze continuous images. A computer will automatically analyze digital images and store only the data actually showing birds striking or coming in close proximity to the wires.

Power supply options to be considered include conventional alternating-current electrical service and photovoltaic solar cells. Communication options to be investigated for transmitting data from the sensor system to the monitoring site include radio link, telephone lines, and cellular communication.

Task 4: Fabricate, Acceptance Test, and Refine Prototype Sensor System

At the completion of the R&D phase, a prototype BAM will be fabricated for evaluation and testing in a mock field setting. EDM will fabricate, acceptance test, and refine a prototype sensor system. The fabrication effort will include the integration of the sensor package, power supply, communication system, and enclosure/deployment hardware. This task will also include the development of the system firmware. The completed system will be thoroughly tested in a laboratory setting. Based on the results of the acceptance testing, the sensor system design and prototype system will be refined as needed to address any critical problems observed with regard to system accuracy, integrity or reliability. The advanced prototype will be used in the field-testing. The results of this task will be reviewed with the TAG.

Task 5: Field Test and Refine System

The key objective of this phase is to utilize the BAM to capture information on avian wildlife activity in a real world setting. The envisioned monitors will capture, store, and/or transmit images of the interaction of birds with power lines when their flight paths are in close proximity to lines that have monitors installed. A secondary objective is to test the prototype BAMs in order to enable further refinement of the system design.

Five systems will be fabricated and deployed (with Western Area Power Administration [Western] line crew assistance) on selected spans at the Audubon National Wildlife Refuge. Western will also supply AC power for the units. In addition to developing and deploying the systems, EDM will support the use of the monitors following the installations.

Task 6: Field Monitoring

Data acquired in previous years from dead-bird searches and BSI evaluations will be used to develop a deployment plan for prototype BAM units at the Audubon National Wildlife Refuge. After the BAMs are installed, concurrent monitoring using dead-bird searches, BSI and BAM will continue for one year to test effectiveness of wire marking and to assist in evaluating performance of the BAM. The first year of the BAM field trial is proposed to overlap with the final year of the BSI field trial. During this period BAM images shall be compared to BSI data to determine the effectiveness of the BAM. The BAM Project shall then need at least one additional year of dead bird searches for comparison with data from the BAM.

The project team shall analyze data collected by the monitors to determine if birds are colliding with overhead static wires or primary conductors. The project team shall also document the number and species of birds involved, weather, and time of day of observed collisions.

4
MITIGATING BIRD COLLISIONS WITH POWER LINES

The first two years of the BSI Project included dead bird surveys to document annual numbers and spatial distribution of avian fatalities at the North Dakota study site. These data along with information on bird species and time of day, plus weather covariate data will provide the basis of recommendations for appropriate mitigating measures (e.g. aerial marker spheres, swinging plates, artificial lighting, spiral vibration dampers, and bird flight diverters).

Line marker effectiveness will be estimated by the change in collision frequency between treatment and control spans using a crossover design (Ratti and Garton 1994). Crossover involves reversing the pattern of control and treatment for experimental units (transmission-line spans). The first two years of dead bird searches provided pretreatment avian fatality data that will be used to develop the experimental design for testing marking efficacy. During the experimental phase of the study Western will mark wires in treatment-group spans while another group of spans will remain unmarked to serve as experimental controls.

Because year-by-span fatality data can be highly variable (see Chapter 6), simulations will be conducted to develop an experimental design with adequate statistical power for detecting likely differences between marked and unmarked spans at the causeway. This work has not been conducted but we speculate that four (two-by-two year crossover) or more years may be required past the pretreatment period to ensure reliable inferences from project results. Duration of the marking study is the only factor relating to sample size that can be adjusted to ensure reliable results – number of spans (experimental units) is fixed and numbers of dead birds occurring annually at the causeway cannot be controlled. It is far better to invest in quality research with adequate sample sizes than to conduct small-scale projects where the end result is little better than unsubstantiated speculation due to insufficient sample sizes.

The scenario proposed above will allow for cost sharing between the wire marking study and BSI and BAM evaluations. If the marking study extends beyond the BSI and BAM evaluation period, separate budgeting may be required to complete the marking study. A budget proposal will be prepared after the experimental design has been identified.

5
ESTIMATING NUMBERS OF BIRDS KILLED BY COLLISION WITH POWER LINES

It is difficult to reliably estimate absolute numbers of birds killed by collision with power lines ("wire strike") using counts of dead birds found near power lines because of biases inherent in such surveys. Rather than attempting to estimate absolute levels of avian fatality, our approach involves reliably estimating a span-specific index of fatalities caused by wire strike that can serve as a response variable for estimating efficacy of wire marking and as an aid in evaluating the BSI and BAM. Primary data consist of counts of dead birds obtained from intensive surveys near power lines and biases associated with search efficiency and scavenging of carcasses. Wire marking will be evaluated by comparing groups of spans with either marked or non-marked wires. Wire strikes detected by the BSI and BAM will be compared with span-specific values of bias-adjusted counts of dead birds ("adjusted counts"). Supplemental methods using intensive observation of one span may be used to evaluate the BSI and BAM, and these instruments may provide an independent data set for evaluating wire marking.

Study Site

The primary study site is located approximately 65 mi (105 km) north of Bismarck, North Dakota, at the Audubon Causeway ("causeway"). The causeway is orientated approximately north-south and lies between Lake Sakakawea and Lake Audubon (west and east of the causeway, respectively). U.S. Highway 83 (four lanes), a railway line (one set of tracks), and a multi-circuit electrical transmission power line parallel one another along the causeway. The power line segment of interest is approximately 2.4 mi (3.9 km) long and consist of two 115 kV (Western) and one 41.6 kV (Otter Tail Power Company) circuits supported by steel-lattice towers approximately 130 ft (40 m) tall, in 13 spans. We arbitrarily designate span numbers from the south end of the causeway, with span 1 bounded by structures 12/5 to 12/6 (Table 5-1).

Spans 2–11 are consistent with respect to structure and wire configuration (Figure 5-1), number of wires (Table 5-1), and underlying topography. All have open water on both sides of the causeway, except Span 11 has some dry land west of the causeway. Characteristic features of the causeway from west to east are Lake Sakakawea, very large rock riprap sloping up to the top of the causeway, a single railway on typical crushed rock bed, shallow grassy ditch with standing water in some locations, paved four-lane highway, continuous guard rail at edge of paved shoulder, a narrow strip of sparsely vegetated ground, smaller rock riprap sloping down to Lake Audubon. Topographic and habitat characteristics of Span 1 and Span 13 are more similar to each other than to other spans at the study site because they include considerably more dry land.

Table 5-1
Characteristics of Spans at the Transmission Line Segment at Audubon Causeway in Central North Dakota

Span Number	Structure Numbers	Span Length ft (m)	Number of Wires		
			41.6 kV	115 kV	
				Conductors	Ground
1	12/5[1]–12/6	931 (283.8)	3[2]	6[3]	2[3]
2	12/6–12/7	930 (283.5)	3	6	2
3	12/7–13/1	936 (285.3)	3	6	2
4	13/1–13/2	934 (284.7)	3	6	2
5	13/2–13/3	1000 (304.8)	3	6	2
6	13/3–13/4	1000 (304.8)	3	6	2
7	13/4–13/5	1000 (304.8)	3	6	2
8	13/5–14/1	1000 (304.8)	3	6	2
9	14/1–14/2	1025 (312.4)	3	6	2
10	14.2–14/3	1030 (313.9)	3	6	2
11	14/3–14/4	865 (263.7)	3	6	2
12[4]	14/4–14/5	997 (303.9)	3	6 & 3[5]	2
13	14/5–14/6	1053 (303.9)	3[6]	3	2

[1] Two steel lattice towers (12/5, Figure 5-2) carrying separate 115 kV lines with conductors in horizontal plane transition to single steel lattice tower (12/6, Figure 5-1) carrying conductors for both 115 kV lines in vertical orientation.

[2] The 41.6 kV line is supported on wood pole structures closely paralleling highway until transitioning to lattice arm cantilevered to east from Structure 12/6 (Figure 5-1 and Figure 5-2).

[3] Heights, orientations, and numbers of wires for Span 1 are unique among the 13 spans.

[4] A substation was built between structures 14/4 and 14/5 after original construction of the line. An intermediate tower was built inside the substation, so Span 12 is composed of 2 subspans (Figure 5-4).

[5] One of the 115 kV lines terminates at the substation and the subspan north of the substation has only 3 conductors.

[6] The 41.6 kV line is supported by wood pole structures north of structure 14/5.

Figure 5-1
View of Causeway from Meadow at Span 1, Looking at Span 2 (in foreground) with Towers Typical of those in Spans 2–12

Span 1 (Figure 5-2) crosses a large meadow with little woody vegetation but Span 13 (Figure 5-3) includes several rows of planted deciduous trees and a large pond that may be dry in some years. Spans 1 and 13 also differ in number of wires present (Table 5-1). Span 1 is transitional from two relatively short steel lattice towers (one for each 115 kV line with horizontally orientated conductors) to a single taller steel lattice tower (12/6) with conductors from each 115 kV line rotated to vertical orientation. Span 13 is also transitional between vertical orientation of 115 kV wires at tower 14/5 and horizontal orientation at tower 14/6.

Figure 5-2
Aerial View (to Northwest) of Span 1 where Two 115 kV Lines Transition from Structures 12/5 at Left to Single Structure 12/6, just Visible at Right. The 41.6 kV Line Supported by Wood Poles Parallels the Highway and Transitions to Structure 12/6. Lake Audubon is in Foreground and Lake Sakakawea in Background

Figure 5-3
Aerial View (to Northwest) of Span 13 showing Meadow, Tree Rows, and Pond East of Power Line. Single 115 kV Line Transitions from Vertical to Horizontal Orientation and 41.6 kV Line Transitions to Single Wood-pole Structures

Span 12 is really two spans of unequal length with different numbers of wires present in each (Table 5-1) due to the presence of a substation (including an intermediate tower) between towers 14/4 and 14/5 (Figure 5-4). Span 12 is topographically complex and non-uniform along its length. It is not similar to any other span at the study site and the two sub-spans are not similar to each other in either length or number of wires present because one of the 115 kV lines terminates at the substation (Table 5-1).

Figure 5-4
Aerial View (to Northwest) of Span 12 showing Irregular Topography and Subspans Resulting from Construction of the Substation. One 115 kV Line Terminates at the Substation

Spring and autumn migrations bring thousands of birds through the area. Lake Audubon, Lake Sakakawea and adjacent shoreline habitats attract waterfowl, pelicans, gulls, terns, grebes, cormorants, and various shore birds and passerine species. Many of these birds remain during summer to nest and rear young. Activities of migrating birds, adults foraging to provision hatchlings, and recently fledged young birds learning to fly all contribute to the risk of birds encountering and colliding with wires along the causeway. However, vehicle traffic on U.S. Highway 83 also poses collision risks for low-flying and scavenging birds at the causeway.

During 11 days, from 31 May through 24 August 1976, McKenna and Allard (1976) found 244 dead birds on U.S. Highway 83 at the causeway. They assumed these birds were killed by collision with power lines paralleling the highway, but did not provide direct evidence of collision with wires. During subsequent years, personnel at Audubon National Wildlife Refuge have casually documented birds found on the causeway by date, species, and general location. For example, 23, 56, 36, and 66 dead birds were observed (March–December) when driving across the causeway during 1995, 1996, 1999, and 2000, respectively (P. Smith, unpublished data, United States Fish and Wildlife Service). Clearly, birds are being killed along the causeway and the numbers documented above are only minimum estimates because of spatial and temporal limitations of previous casual surveys and biases inherent in counting dead birds.

We use a reference study site north of the causeway (where large ponds and wetland habitat are adjacent to U.S. Highway 83) for assessing the relative contribution of vehicle collisions to overall fatality numbers observed at the causeway. We have delineated seven sections of highway ("pothole transects") that total approximately 2.3 mi (3.7 km) compared to 2.4 mi (3.9 km) at the causeway. The reference site begins 4.1 mi (6.6 km) and ends 13.6 mi (21.9 km) north of causeway Span 13 (Table 5-2).

This reference site was selected because highway traffic is likely the dominant avian mortality factor there. Although there is a power line along the highway, there are fewer wires and they are much lower than at the causeway. The 41.6 kV line at the causeway approximately follows the highway through the reference site. This line is approximately 90 ft (27 m) west of the highway and the three wires are supported at approximately 32 ft (9.8 m) above the ground. The single 115 kV line diverges far from U.S. Highway 83 north of the causeway and is not present at the reference site. Because the wires present at the reference site are relatively low and far from the highway, we assume that few birds that strike wires will land on the highway.

Methods

To obtain unbiased estimates of total number of avian fatalities it is necessary to properly adjust numbers of dead birds found for biases such as search (birds within search area missed by searcher), removal (birds removed by scavengers before search occurs), habitat (birds missed because area within a designated search area was physically or otherwise not searchable), and crippling bias (birds that collide with lines but do not fall within the search area [Faanes 1987, Hartman et al. 1993, Avian Power Line Interaction Committee, APLIC, 1994]). These biases cause observed counts to be lower than actual number of birds killed or number of collisions. Additionally, inclusion of birds killed by causes other than collision with wires (or support structures) will bias counts. Obtaining unbiased estimates of total collisions from dead-bird searches is typically infeasible from logistical and financial perspectives, particularly because of difficulties in estimating crippling bias. Therefore, our primary objectives will be obtaining reliable estimates of combined effects of search and removal biases, obtaining counts of dead birds that constitute a high proportion of total dead birds within searchable areas, and in eliminating birds not killed by line collision from counts. This approach will enable estimating likely minimum numbers of birds killed (total and by span), which can be used in selecting appropriate spans for testing BSI and BAM, and can be compared with data obtained using BSI and BAM to aid in field verification of these systems. These estimates will also be used for designing an experimental study to determine effectiveness of collision mitigation and for analyzing the resulting data.

Table 5-2
Pothole Transect Locations from Intersection of U.S. Highway 83 and State Highway 37

Transect	Stake	Odometer[1]	Comment
		0.0	U.S. 83 and ND 37 intersection (Garrison turnoff)
A	South	1.6	By reflector post
	North	2.0	By “Stop” sign
B	South	2.55	Corner fence post at turnout
	North	3.2	By curve sign
C	South	3.6	By reflector post
	North	3.7	By reflector post
D	South	4.1	By “Stop” sign
	North	4.5	By reflector post south of mile marker 164
E	South	6.5	By reflector post
	North	6.7	By reflector post
F	South	7.85	By reflector post
	North	8.15	By reflector post
(For Reference)		8.55	Cemetery west of U.S. 83
G	South	10.8	By “One Way” sign
	North	11.1	By reflector post
(For Reference)		12.4	U.S. 83 and ND 53 intersection, just before Max

[1] From USFWS Ford Ranger pickup odometer, 2002.

Statistical Methods

Background

APLIC (1994) summarized various causes for undercounting dead birds and described four primary biases, how they are estimated, and how they are used to adjust raw count data to obtain an estimate of total collisions (ETC):

$$ETC = TDBF + SB + RB + HB + CB \text{ (APLIC 1994:39),} \qquad \textbf{Eq. 5-1}$$

where $TDBF =$ total dead birds found, $SB =$ search bias, $RB =$ removal bias, $HB =$ habitat bias, and $CB =$ crippling bias. Planted birds are used in blind trials to estimate search and removal biases. An assistant places birds (of same species, sex, etc. as those colliding with wires) within searchable portions of an overall search area at locations unknown to the searcher. The proportion of planted birds found is an estimate of the proportion of collision victims occurring within the search area that are found. Planted birds are similarly used to estimate the proportion of birds not removed by scavengers. Further:

$$SB = \left(\frac{TDBF}{PBF}\right) - TDBF \text{ (APLIC 1994:37),} \qquad \textbf{Eq. 5-2}$$

$$RB = \left(\frac{TDBF + SB}{PNR}\right) - (TDBF + SB) \text{ (APLIC 1994:38),} \qquad \textbf{Eq. 5-3}$$

$$HB = \left(\frac{TDBF + SB + RB}{PS}\right) - (TDBF + SB + RB) \text{ (APLIC 1994:38)} \qquad \textbf{Eq. 5-4}$$

$$CB = \left(\frac{TDBF + SB + RB + HB}{PBK}\right) - (TDBF + SB + RB + HB)$$
$$\text{(APLIC 1994:39),} \qquad \textbf{Eq. 5-5}$$

where $PBF =$ proportion of planted birds found during blind trials (an estimate of "detection probability"), $PNR =$ proportion of planted birds not removed by scavengers (an estimate of carcass "scavenging survival"), $PS =$ proportion of formal "search area" that is searchable, and $PBK =$ proportion of observed collisions falling within the search area.

Sampling Error

The proportions PBF , PNR , and PBK are estimates obtained from a sample and therefore exhibit sampling error (difference between true population proportion and sample proportion). The calculated value of ETC also has sampling error because it is a function of estimated proportions PBF , PNR , and PBK , all of which have sampling errors. Because PS is not estimated from a sample it does not have sampling error. It is important to realize that sampling error has nothing to do with errors in methodology or measurement, but results simply from the use of a subset or sample of the full population to estimate a parameter of interest.

Reported values of ETC should always be accompanied by error estimates to allow informed decisions on reliability of study results. Through algebraic substitution and rearrangement, Equation 5-1 can be expressed as:

$$ETC = \frac{TDBF}{PBF \times PNR \times PS \times PBK} \qquad \textbf{Eq. 5-6}$$

Sampling variance for a proportion (p) is known to be $p(1-p)/n$ (Sokal and Rohlf 1995), so sampling variances for PBF , PNR , and PBK can be estimated, where $n =$ sample size (of planted birds or total collisions observed) used to estimate PBF , PNR , and PBK . Given estimates of $\mathrm{var}(PBF)$, $\mathrm{var}(PNR)$, and $\mathrm{var}(PBK)$, the component of variance of ETC from estimating these proportions (assuming independence among PBF , PNR , and PBK) can be estimated using the "delta method" (Seber 1982) as:

$$ETC^2 \left[\frac{\mathrm{var}(PBF)}{PBF^2} + \frac{\mathrm{var}(PNR)}{PNR^2} + \frac{\mathrm{var}(PBK)}{PBK^2} \right].$$

Sampling variance is an unavoidable nuisance factor associated with the sampling process that reduces value of results by introducing random error, and increases risk of drawing incorrect conclusions. Minimizing sampling error increases reliability of results. It is clear that $\mathrm{var}(ETC)$ increases with the number of estimated proportions used to adjust $TDBF$ because their variances are additive. It is less clear, but also important, that proportions should be based on reasonably large samples and that each proportion is as large as possible. Variance of a proportion decreases as sample size increases, is maximum for $p = 0.5$ (for a given sample size), and approaches 0 as p approaches 1.

Estimating Number of Dead Birds Using One Bias Factor

One approach for improving precision of estimating number of dead birds is to reduce the number of estimated proportions used to adjust counts of dead birds. We propose a sampling plan to enable estimating a single proportion that combines detection probability and scavenging survival into a single probability of recovering a dead bird if it exists within search areas (r, sampling plan discussed in a later section).

Any incomplete count (C) can be adjusted by an estimate of the recovery probability ($\hat{r}$) to obtain an adjusted count:

$$(\hat{N} = C/\hat{r}), \qquad \textbf{Eq. 5-7}$$

where a caret or "hat" indicates an estimated parameter, $\hat{N}$ is interpreted as the estimated number of dead birds that occurred inside search areas during a given time period, and $\hat{r}$ is the proportion of planted birds that are recovered.

An approximate variance of $\hat{N}$ is (Thompson 2002):

$$\hat{\mathrm{var}}(\hat{N}) \approx \frac{\hat{N}(1-\hat{r})}{\hat{r}} + \frac{\hat{N}^2\,\hat{\mathrm{var}}(\hat{r})}{\hat{r}^2}. \qquad \textbf{Eq. 5-8}$$

An approximate confidence interval for $\hat{N}$ is:

$$\hat{N} \pm \hat{\mathrm{se}}(\hat{N})\ \ t_{\alpha/2,df}, \qquad \textbf{Eq. 5-9}$$

where

$$\hat{\mathrm{se}}(\hat{N}) = \sqrt{\hat{\mathrm{var}}(\hat{N})}, \qquad \textbf{Eq. 5-10}$$

and $t_{\alpha/2,df}$ is the value from a cumulative t distribution at α probability and degrees of freedom $df = n$-1, and n = sample size used to estimate $\hat{r}$.

Using the joint estimator will increase precision of estimated total collisions. For example, in a series of cases comparing the use of r only, and PBF and PNR together, reductions in $\mathrm{se}(N)$ ranged 8%–26% (r: 0.49–0.90, N: 50–500, and n_r: 50–500) for the combined estimator, assuming $n_r = n_{PBF} + n_{PNR}$, $n_{PBF} = n_{PNR}$, $PBF = PNR$, and $r = PBF \times PNR$.

Estimating Recovery Rate

Essentially, wire marking efficacy will be evaluated by changes in estimated numbers of dead birds over time for marked and unmarked spans. Evaluations of BSI and BAM will depend on correlations involving span-specific estimates of dead birds. Therefore, we are primarily interested in estimating r to get the best estimate of N for each span. The way estimates of r are obtained from the data will strongly influence span-specific estimates of N. We use modeling to structure existing data in various ways to estimate r. The goal of modeling recovery rates is to ensure that estimated numbers of dead birds/span for each year are closer to "truth" than unadjusted counts, and as close to "truth" as possible given the data from planted birds.

Certain models are intuitively appealing, primarily for directness and simplicity. For example, an obvious model to consider gives a separate recovery rate for each span in each year based on a simple average of recovered = 1 and not recovered = 0 data for each bird. Other simple models of this sort include estimating a different recovery rate for each year that is constant among spans, a different recovery rate for each span that is constant between years, and a single recovery rate that is constant among years and spans. Estimates from these models could be used directly with equations 5-7and 5-8 and provide potentially reasonable adjusted counts, depending on how close these recovery-rate estimates are to "truth". A single estimate of recovery rate across years and spans would be especially fortuitous because comparisons among spans and years could be made without adjusting for recovery rate. However, these are not the only models that should be considered, because they ignore factors that may strongly influence recovery rates in ways that require variable adjustments among spans and years. Estimates of numbers of dead birds existing in search areas may be biased low if count data are adjusted by this simple estimate of recovery probability if the true probability of recovery is different for each bird or group of birds.

The true underlying recovery probability is likely different among bird species or groups of similar species, depending on various factors such as inherent visibility of the bird, how habitat features influence visibility, scavenger preference for different size or species of bird, and how efficient each observer is at detecting birds. Inherent visibility of a bird is largely a function of its size and coloration. Other factors being equal, small drably colored birds are harder to see than large brightly colored birds. Habitat features, essentially surface roughness represented by rocks and vegetation, can reduce visibility of birds that would be easily detected on a smooth, flat surface (by people and scavengers). Scavengers may be more likely to completely consume or remove smaller birds. Also, effects of scavenging will not be uniform if scavengers are not uniformly distributed across the search area. Avian scavengers may be approximately uniformly distributed along the causeway, but mammalian scavengers may be less frequent near the center than near ends of the causeway. Because different people searched for birds in different years, we may expect to see differences in recovery rates between years attributable to different levels of search efficiency.

Sightability models are sometimes used to adjust incomplete counts of animals by accounting for effects of relevant covariates in logistic regression models (Samuel et al. 1987, Steinhorst and Samuel 1989), where sightability is analogous to recovery rate. We used logistic regression (PROC GENMOD, SAS Institute 1999) to model recovery rate as a function of classification and continuous variables that potentially influence recovery rate, and AIC model selection to evaluate competing models (Burnham and Anderson 1998). The form of the global (most general) model was:

$$\text{logit}(\hat{r}_i) = \text{intercept} + year_i + span_i + tvis_i + dends_i + blen_i + blen_i \times tvis_i, \qquad \textbf{Eq. 5-11}$$

where $\text{logit}(\hat{r}_i) = \log_e[\hat{r}_i \,/\, (1 - \hat{r}_i)]$; $\hat{r}_i$ = estimated probability that planted bird i was recovered, given its specific values for main effects and interactions (i = 1–354). Main effects consisted of *year* = effect term for year (2001, 2002); *tvis* = effect term for transect-specific recovery rates; *span* = effect term for span number; *dends* = effect term for distance to nearest end of causeway; and *blen* = effect term for approximate body length for species or species group. Additional, reduced predictor variables included: *vis* = effect term for habitat-related visibility factor (high, low); and *stype* = effect term for end spans (1, 13) versus interior spans (2–12). We subjectively evaluated each two-way interaction and found only *blen*×*vis* and *blen*×*tvis* likely to be important. Various combinations of main effects and interactions were evaluated.

We interpret the *year* term as relating primarily to observer differences but these are confounded with other year-specific factors such as prolonged severe weather that could also influence recovery rates. *Tvis* is a classification variable representing effect of terrain on visibility of birds for different transect types. Flat, mostly barren areas were classified as high visibility (highway, dirt strip, gravel road, substation, and parking area). Riprap, meadow, and railway-ditch transects included rocky and-or vegetated areas that reduced visibility of birds and each was modeled separately in *tvis* to allow for visibility differences among these transects. *Vis* is a classification variable where riprap, meadow, and railway-ditch transects were collapsed into a single low visibility classification. *Span* is a classification variable that allows for modeling recovery rates separately for each span. *Stype* is a variable that collapses individual spans into a more likely grouping where end spans are more similar to each other than to interior spans, and different recovery rates between these groups might be expected. *Dends* is the linear distance of each planted bird from the nearest end of the causeway and is included primarily to represent potential differential effects of mammalian scavenging rates from ends to interior. For this analysis, we defined causeway ends as towers 12/6 and 14/5 (encompassing Spans 2–12) and birds planted in Spans 1 and 13 were assumed to be at the end of the causeway (*dends* = 0). *Blen* is the approximate body length for each species (Sibley 2000). We assumed size adequately represented inherent visibility of birds and did not include coloration as a factor.

Models were evaluated using AIC model selection with second-order bias adjustment (AIC_c) where the likely best estimating model has the lowest AIC_c (Burnham and Anderson 1998:51). Models were ranked by AIC_c and differences in AIC_c (Δ_l, for l models) between each model and the highest ranked model were calculated. In general, models with Δ_l values up to about 2 or 3 should be given consideration in the estimation process. Also, relative weight of evidence in favor of each model can be estimated. Weighting factors (Akaike weights, w_l) express the weight of evidence in favor of each model as the best within a set of candidate models (Burnham and Anderson 1998:124):

$$w_l = \frac{\exp\left(-\frac{1}{2}\Delta_l\right)}{\sum_{l=1}^{L}\exp\left(-\frac{1}{2}\Delta_l\right)} \text{, and} \qquad \textbf{Eq. 5-12}$$

$$\sum_{l=1}^{L} w_l = 1. \qquad \textbf{Eq. 5-13}$$

Unless the highest-ranked model is clearly superior to the next several models (for example, $w_1 >> w_2$), it is often advantageous to consider a subset of the highest-ranked models for parameter estimation.

Given a subset of L' estimating models and associated w_l weights calculated for that specific set of models, individual-specific values of predictor variables can be used to estimate a recovery rate for the j^{th} dead bird found at the causeway (Burnham and Anderson 1998:133):

$$\hat{r}_{L',j} = \sum_{l=1}^{L'} w_l \hat{r}_{l,j}, \qquad \textbf{Eq. 5-14}$$

where $\hat{r}_{l,j}$ is the model- and bird-specific estimate on the scale 0–1:

$$\hat{r}_{l,j} = \frac{\exp[\text{logit}(\hat{r}_{l,j})]}{1+\exp[\text{logit}(\hat{r}_{l,j})]}, \qquad \textbf{Eq. 5-15}$$

and j designates dead birds originally found during searches (in contrast, i designates birds placed for bias estimation).

The adjusted value for each bird found is given by $1/\hat{r}_{L',j}$, and the adjusted total for any group of J birds is given by:

$$\hat{N} = \sum_{j=1}^{J} \frac{1}{\hat{r}_{L',j}}. \qquad \textbf{Eq. 5-16}$$

This estimator differentially adjusts count data among groups (for example, annual span-specific counts) for effects of terms in the selected model(s) for recovery rate. Equations 5-14–5-16 also apply if only the single best model is used for parameter estimation (that is, when L'= 1 and $w_1 = 1$).

A variance estimator for Equation 5-16 is under development, so methods for standard errors and confidence intervals for adjusted numbers of dead birds are not presented this interim report.

Field Methods

Dead-Bird Searches

We search for and collect dead birds between structures 12/5 and 14/6 (see Appendix C for details on search protocol). Searchable areas under and adjacent to the line are broken into transects. Most spans (2–11) are of similar configuration, length, and underlying topography and vegetation conditions (Figure 5-5). Area on the causeway searchable for dead birds is covered by five transects paralleling the transmission line and U.S. Highway 83. The east side of the search zone consists of two parallel transects (approximately 25-ft [7.62 m] wide) on the sloped rock riprap (“lower-riprap transect” is farthest east and adjacent to Lake Audubon, “upper-riprap transect” is adjacent to and west of the lower riprap transect). Between the upper riprap transect and the paved surface of U.S. Highway 83 lays a narrow strip of bare earth and sparse vegetation that is searched separately (“dirt-strip transect”). The entire paved surface of Highway 83 constitutes a transect (“highway transect”) and the area between the highway and west riprap containing a shallow vegetation-covered ditch and rail line constitutes the fifth transect (“railway-ditch transect”).

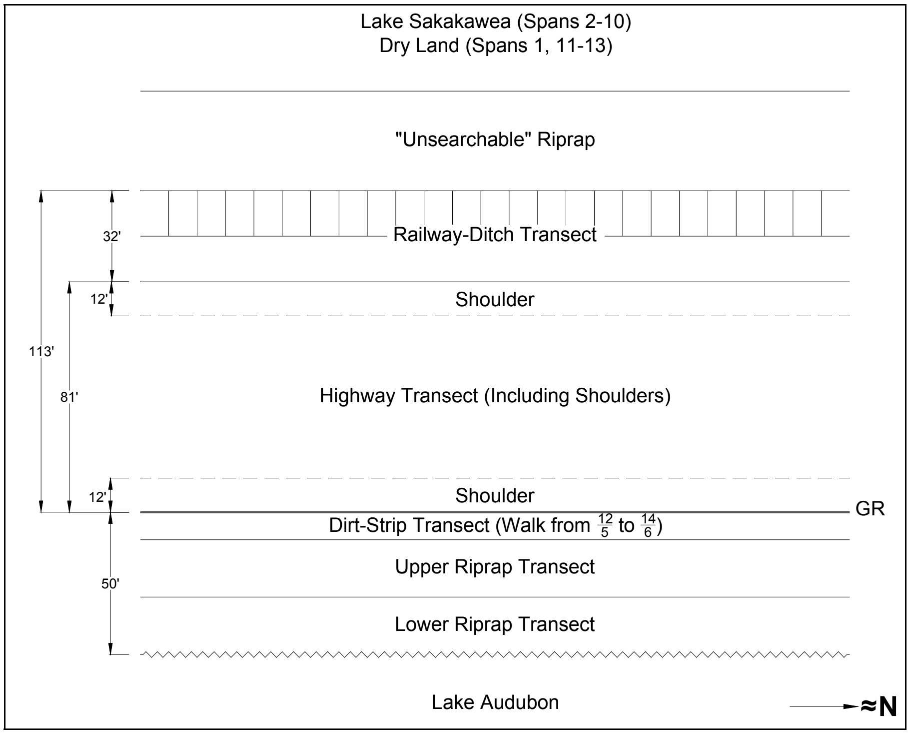

Figure 5-5
Schematic of Causeway at Spans 2–11 Showing Five Transects Delineated for Dead Bird Searches. Railway-Ditch, Highway, and Dirt-Strip Transects are Also Common to Spans 1, 12, and 13. Locations of Dead Birds found at all Spans are Recorded Relative to South Tower in Span, and to Guardrail (GR)

All transects except the highway are searched on foot once every three–four days. The highway transect is searched twice daily, at first light and shortly before dark. Several reasons justify the relatively intensive search effort on the highway. First, birds landing there are likely to be struck by vehicles, displacing them from their landing point and reducing their value for necropsy and bias estimation, so birds on the highway should be collected as frequently as possible. Also, twice-daily searches indicate proportions of collisions occurring in daylight and darkness, which may have important implications for the marking study and for field evaluation of BSI and BAMS. The highway transect at the causeway is searched by vehicle and requires relatively little time/search. Transects at the reference site are highway transects only and are similarly searched by vehicle.

Searching riprap transects is challenging because of potential difficulties in observing birds that fall or retreat into deep crevices between rocks. Sampling the riprap must balance tradeoffs between increasing time/riprap transect search (to increase detection probability) and decreasing time/riprap transect search to decrease interval length between searches and, thereby, increase probability that birds falling in riprap are not removed by scavengers before at least one search is conducted. Ideally, both of these probabilities should be high and approximately equal. Safety is the primary emphasis while actively moving about in the riprap, so search time is segregated from travel time. This necessitates searching for birds while stationary at many closely spaced points within each riprap transect. We search at points spaced at 25-ft (7.62 m) intervals along the centerline of each riprap transect. Search protocol at each point consists of concentrated search within an approximate 25-ft (7.62 m) radius in a full circle around each point. This results in overlapping coverage from different viewing angles to increase detection probability. Our objective is to maximize search effort without increasing intervals between searches beyond four days. This sampling plan represents the most intensive search effort likely feasible without greatly increasing time intervals between consecutive searches.

We consider riprap on the west side of the causeway as “unsearchable”. It is composed of larger rocks than on the east side so dead birds are relatively more difficult to find. Also, because it is farther from the line, it probably contains fewer birds than riprap under the line. Relatively low visibility of bird carcasses and potential sparseness of data lead us to conclude that searching the west-side riprap is not an effective use of project resources.

Spans 1 (Figure 5-6), 12 (Figure 5-7), and 13 (Figure 5-8) need to be monitored because they occur in potentially heavily used flight corridors along lake shorelines at south and north ends of the causeway. However, each of these spans is unique and differs importantly from Spans 2–11, so modified search procedures are required. Essentially, we combine point transects (in riprap areas) and zigzag continuous linear transect search patterns in meadows. Additional named transects include the “substation perimeter transect” and “gravel road transect” associated with the substation. Data collected at these spans may not be directly comparable with that from the causeway spans, may require independent bias estimation, and ultimately may not contribute to some analyses.

Dead birds observed in Lake Audubon are recovered if possible (using an extendable hot stick), documented similarly to those found in transects, and removed. Use of birds removed from the lake is limited in analysis to applications not requiring assignment to a specific span. Use of birds found in the riprap within 3 ft (0.91 m) from the waterline is similarly limited in analysis because of potential that such birds originated in the lake and were thrown onto the bank by wave action. It may be possible to use recent weather data to “accept” or “reject” such birds for use in specific analyses.

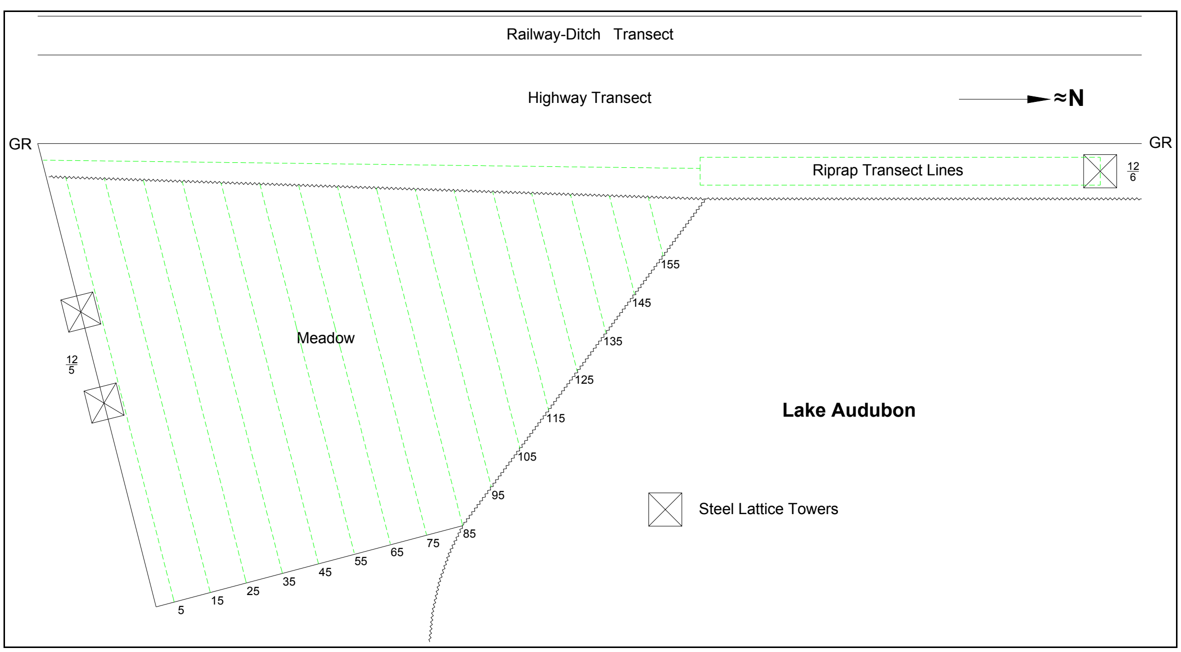

Figure 5-6
Schematic of Span 1 showing Meadow and Riprap Transect Lines (Dashed Lines).

Dirt-strip (not shown) East of Guardrail (GR) is also a Walking Transect in Span 1. Eastern Boundary of Meadow Search Area Extends 164 ft (50 m) from the Outer Conductor. Meadow Transect Line Spacing shown in Meters

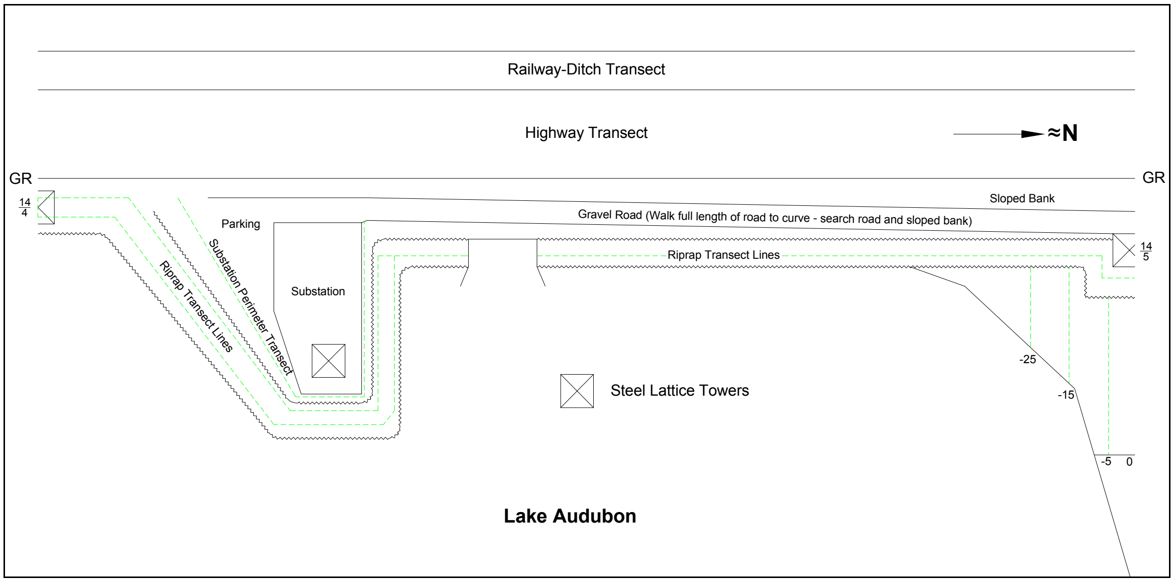

Figure 5-7
Schematic of Span 12 Showing Riprap and Substation Perimeter Transects and Transect Lines through Small Woodlot at North End of Span (Dashed Lines). Dirt Strip (not shown) East of Guardrail (GR) and Gravel Road are also Walking Transects in Span 12

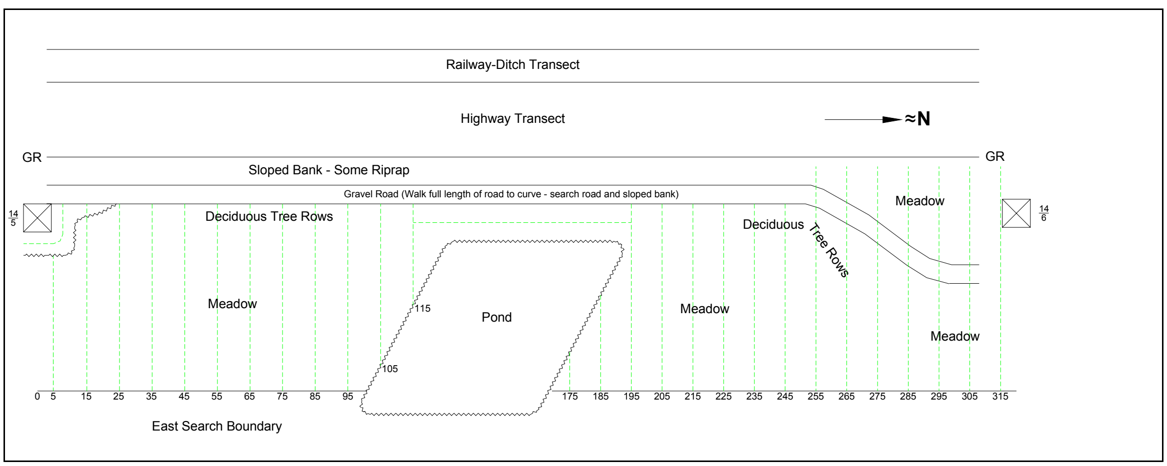

Figure 5-8
Schematic of Span 13 Showing Meadow Transect Lines (Dashed Lines) with Spacing shown in Meters. Dirt Strip (not shown) East of Guardrail (GR) and Gravel Road are also Walking Transects in Span 13. Eastern Boundary of Meadow Search Area Extends 164 ft (50 m) from the Outer Conductor

Other dead animals and garbage that might attract scavengers (particularly food and food wrappers) are removed from transects for disposal at the Refuge. Objectives are to minimize scavenging of bird carcasses in general by reducing overall level of scavenger attractants, and to reduce potential for vehicle collision with avian scavengers attracted by food items located on or near the highway. All foreign objects found on highway, ditch, and dirt strip transects are removed to eliminate distraction when conducting driving searches for birds.

Direction of travel and order of transects searched each day were systematically varied to minimize potential biases. In 2001, one person conducted all searches but in 2002 two persons conducted searches to intensify search effort and to increase safety on the riprap. Meadow transect lines searched in 2001 were spaced at 32.8 ft (10 m), but in 2002 the two searchers walked in tandem, spaced at 16.4 ft (5 m). Although search effort was more intense in 2002, results among years are comparable because of intensive efforts to estimate recovery rates. More intensive search effort should improve detection probability (primarily in meadows because of reduced spacing between transect lines) and carcass survival probability (because of reduced time between searches of individual transects for scavengers to remove dead birds).

Search and Removal Biases

Marked bird carcasses are placed within searchable areas (except traffic lanes of highway transect) to jointly estimate effects of search and scavenging removal biases (Faanes 1987, Hartman et al. 1993, APLIC 1994) or, specifically, $\hat{r}$. We attempt to maximize numbers of birds planted during each field season to improve precision of estimates of joint detection-survival probability. Approximate sample sizes of 100, 45, and 25 are necessary to estimate a 95% confidence interval on a proportion of approximately ±2se, ±3se, and ±4se (se = standard error), respectively, if the true proportion is 0.5. Tighter confidence intervals result from equivalent sample sizes as the proportion increases or decreases away from 0.5. Estimation of the joint probability of detection and carcass survival also improves precision of estimates.

Random numbers of birds (between 0 and some upper limit unknown by the searcher) are planted daily at random times and locations within searchable areas (except travel lanes of the highway transect). Number of birds/day is generated from a Poisson distribution scaled to maintain approximate balance between incoming and outgoing plantable birds. Plantable birds are defined as those that are found essentially intact (not scavenged or severely damaged by vehicles) and freshly killed (not severely decomposed). Individual birds are selected by uniform random sampling from the full candidate pool of plantable birds. Planting locations are uniform-randomly selected from a candidate pool of 10 ft (3.05 m) × 10 ft (3.05 m) cells within span-specific searchable areas. Probabilities of selecting cells within 100 ft (30.48 m) of the centerline of the power line and between 100 ft (30.48 m)–200 ft (60.96 m) of the centerline are weighted by a factor of 3 and 2, respectively, relative to cells >200 ft (60.96 m) from the centerline. Approximately equal numbers of birds are planted in each of Spans 2–12, and approximately twice the number of birds are planted in each of Spans 1 and 13. The rationale for this allocation is that Spans 1 and 13 are more similar to each other than to Spans 2–12 and may require independent estimation of recovery rate, thus requiring larger sample sizes. Dead bird planting lists are generated once/week or once/2 weeks to stay current with the available pool of birds available for planting.

Beak, toe, and wing clipping is used to differentiate planted birds from “naturally” occurring carcasses. For each planted bird approximately half the beak, all toe claws, and approximately

0.5 in. of primary and secondary feathers on each wing is clipped. Each bird is individually identified by wrapping freezer tape around the featherless tarsus of each leg. Five completely overlapping wraps of tape with bird number written on each layer is sufficiently durable without making the bird more conspicuous to scavengers. Planted birds retain the same identification number assigned when originally found.

Planting locations are based on the same span-specific X-Y coordinate system of distance from the south structure and distance and direction from the highway guardrail used to describe locations of birds found in dead-bird searches (Appendix C). Bird planting entails finding the planting location and tossing the bird approximately straight up in the air to simulate a freefall landing of a bird killed by striking an overhead wire.

Birds are planted without knowledge of searchers concerning number, location, and timing of bird plantings (blind trials). All marked birds found by the searchers are recovered and, if not seriously deteriorated, are reused for future planting. Planted birds not found remain in place indefinitely. Previously undetected planted birds may be found at a later time, perhaps because they were moved by scavengers, which is consistent with expectations for collision victims.

Blind trials are important to prevent conscious or unconscious adjustment of effort by the searcher when planted birds are present. Randomizing number, location, and timing of bird planting, and maintaining secrecy are required for conducting blind trials. Random planting times (days) are also critical for unbiased estimation of probability of recovery. Timing between when a bird is planted and when a search of the area subsequently occurs must simulate the random timing of collisions and search, to provide random opportunity for scavenging removal to occur. We compromise this requirement somewhat by randomizing among days but not within days; we do not plant birds while searchers are on the causeway or at night, but do plant birds on all days the computer generates a nonzero number of birds. Planting schedules are typically generated once/week or once/2 weeks.

Habitat Bias

Estimating the effects of habitat bias (i.e., PS) is important primarily for estimating ETC or for adjusting out relative biases among experimental units. Because Spans 2–11 are nearly identical in cross section habitat bias should be equal among these spans. For purposes of evaluating BSI, BAM, and wire marking, data from these units do not require adjustment for habitat bias. Spans 2–11 should be sufficient for evaluating BSI and BAM. Spans 1, 12, and 13 would differ significantly in habitat bias from Spans 2–11, and perhaps from each other. However, control-treatment pairing of Spans 1 and 13 in a crossover design in the wire marking study would likely offset differences in habitat biases for these spans.

Although calculating ETC is not a primary objective of this study, we may acquire sufficient data to justify a rough approximation. We will attempt to estimate an adjustment for habitat bias (due to “unsearchable” areas [Faanes 1987, Hartman et al. 1993, APLIC 1994]) using distributions of dead-bird recovery locations transverse to the line direction, an assumed idealized search area with a lateral dimension calculated as a function of tower height, area of unsearchable habitat within search zone, and numbers of dead birds seen and/or recovered from Lake Audubon.

Recommendations for search-area width provided by APLIC (1994) for transmission lines of various voltages are not directly applicable at Audubon Causeway, because they are based on standard structural configurations and line height above ground for various voltage classes. Towers on the causeway carry two different 115 kV and one 41.6 kV transmission lines and are taller than typical for 115 kV lines, implying that a wider search area would be necessary than that defined by APLIC (1994). This wider search area would probably include the riprap west of the highway and extend some way into Lake Sakakawea. Most of the potential search area east of the line segment along the causeway is water (Lake Audubon). Spans 1 and 13 are adjacent to extensive areas of dry land and we implemented a search area extending 164 ft (50 m) from the outer conductor on the east side of the right-of-way (and to the west edge of the railway-ditch transect on the west side). This corresponds to APLIC's recommendation for 500 kV lines and should be conservatively large.

Birds found in water along the causeway cannot be used for purposes of experimental design or for estimating the response variable in testing mitigation, and both lakes must be considered as "unsearchable" for those purposes, because of difficulty in ascertaining which span was involved (assuming that ultimate cause of death for each bird was collision). However, these data may be useful for estimating a component of habitat bias and for assessing the overall extent of avian collision fatality. It must be recognized that such use requires a questionable assumption of equality between number of birds killed by the power line that were not counted because they floated away from the causeway area, and number that died elsewhere but floated into the causeway area and were counted. Another difficulty with using birds found in the water is that they may not be recoverable. Without ensuring removal or marking of counted birds there is risk of double counting during subsequent daily surveys. We will recover as many birds as possible from water to minimize double counting, for use in estimating search and removal bias, and for necropsies to determine cause of death. Despite the difficulties discussed above, we may be able to estimate a reasonable first approximation to searchable proportion of search area with little field effort beyond that required for documenting counts and estimating search and removal biases.

Crippling Bias

Estimating crippling bias is time consuming, labor intensive, expensive, and most importantly, usually results in small annual sample sizes. In previous studies where attempts were made to estimate crippling bias, relatively little relevant data were obtained/unit time of effort. For example, Padding (1993) reported seeing 40 avian collisions at 2 sites during 3 winters of observation (November-January), Savereno et al. (1996) observed 35 collisions at 2 sites during 3392 observer hours in 3 years, and Crowder (2000) reported seeing 11 collisions in a 6-month field season. These studies emphasized observational effort for documenting avian behavior (including collision) and numbers of birds flying over transmission lines. Although we may need to conduct observations to verify function of BSI and to document avian behavior for final selection of wires to instrument and visually mark, and to test assumptions of independence among experimental units in the marking study, we will probably devote only a small fraction of the time other researchers have for acquiring observational data, and will likely not accumulate significant amounts of observed collision data.

Alternatively, it may be possible to use results from other studies to explore the potential range for *ETC* at Audubon Causeway. APLIC (1994) reported 2 studies that indicated approximately 74% of birds striking wires fall outside of search areas, i.e. 75% for a "small sample of duck flights" (Meyer [1978, cited in APLIC 1994]), and 73% for a "small sample of duck flights" (James and Haak [1979, cited in APLIC 1994]). Despite small samples and species differences among studies, reported estimates of crippling bias from more recent studies are remarkably similar to those reported by APLIC, i.e. 75% (n = 8) and 28% (n = 32) for mergansers at 2 sites (38 % for both sites combined, Padding 1993); 75 % (n = 20) and 73 % (n = 15) for an unspecified mix of birds at 2 sites (74 % for both sites combined, Savereno et al. 1996); and 82% of 11 birds (mostly waterfowl, Crowder 2000). Only Padding's (1993) results differ more than would be expected from sampling variation alone.

Cause of Death

The Audubon Causeway study is driven by the assumption that birds are being killed from hitting power lines along the causeway, so it is important to ascertain causes of death and to estimate the proportion of dead birds found that were likely killed by collisions with wires. It is not sufficient to infer death from wire strike simply because birds are found under the transmission line. Hunter wounding, vehicle collision, poisoning, disease, or other factors may significantly bias counts, and the relative magnitude of such factors should be identified. We are evaluating two different and independent techniques for estimating the proportion of birds killed at the causeway by wire strike and both involve data from causeway and pothole transects: simple, relatively non-intrusive necropsies of birds collected for replanting; and comparisons of numbers of birds found on paved highway surfaces at the causeway and reference sites, adjusted for numbers of low-level bird over flights, vehicle counts, and scavenging rates. Both methods require strong assumptions and may have substantial measurement error. Comparing results from both methods may provide more reliable insight on effects of vehicle collision on causeway counts of dead birds than either could alone.

Simple Necropsies

The purpose of conducting necropsies is to record the types and extents of traumas observable from a relatively simple procedure of limited intrusiveness that will enable an approximate classification of birds among different ultimate causes of death, including wire strike, vehicle strike, and other (unknown, disease, gunshot, etc.). The techniques we use do not constitute a rigorous or formal necropsy; rather an examination intended to provide as much information on type and extent of trauma possible without excessively damaging birds. Subsequent to necropsy, these birds are used for planting on the causeway to estimate search and scavenging biases.

Only specimens acceptable for bias estimation planting are necropsied; birds where the body is intact, the abdominal cavity is not open, and the bird is not deteriorated. Missing appendages (including the head) do not preclude birds from being used for planting or necropsy. Acceptable specimens for replanting are stored in the freezer until removed for necropsy and planting.

Necropsy begins with an external examination of the specimen, recording information on abrasions, lacerations, exposed skin (missing feathers), and exposed flesh (muscle tissue) and missing appendages. The skull, neck, hips, legs, shoulders, spine, and wings are examined (visually and by “feel”) for broken bones. Pressure is applied to the body cavity to detect broken ribs, breastbone, or collarbone.

A limited subcutaneous examination involves partial skinning of the breast and neck followed by a visual examination and limited probing of exposed tissues. Bruising, accumulation of blood, and indentations are noted, including location and proportional area of neck or breast with trauma. Further evidence of small broken bones (sternum, keel, clavicle, coracoid, and ribs) can sometimes be detected at this point.

We expect that birds flying into wires will usually have injuries on their leading surfaces such as head, neck, wings, breast, and anterior portion of the back. Our initial assumption was that wire strikes cause minimal and localized injuries compared to vehicle collisions, and that only vehicle collisions are likely to cause injuries to posterior areas of birds. We have developed preliminary guidelines for classifying cause of death between wire and vehicle collision based on injuries observed with birds found at the reference site (pothole transects), where we anticipate most birds are killed by vehicle collision (Appendix D). As we accumulate further necropsy data from birds recovered at the reference area, we will update the classification criteria.

Criteria used in assigning cause of death based on these necropsies are based on common-sense assumptions. The system is not exact and there is overlap between trauma characteristics that can result from wire and vehicle collisions, especially considering confounding effects of wire-strike victims falling to ground from great heights. Therefore, judgment is required in assessing the overall damage and making a final determination of the cause of death. There may be cases where there is too much damage to classify the cause of death as a power line collision but not enough to classify the cause of death as a vehicle collision, so a classification of “either wire or vehicle” strike is the most the data can support.

Adjusted Dead Bird Counts from Highway Surfaces At Causeway and Reference Sites

We conduct morning and evening highway searches for dead birds on paved surfaces at both the causeway and reference sites (Appendix E). Levels of bird activity and vehicle traffic volumes influence probability of bird-vehicle collision. Given equivalent levels and types of bird activity, traffic volume, and scavenging removal (along with the assumption that vehicles killed all dead birds found at the reference site), we expect to find more dead birds at the causeway than at the reference site–with the difference attributable to wire strikes at the causeway. Because we suspect differences between areas in bird activity, traffic volume, and scavenging removal, we conduct counts of birds flying low over the highway and vehicle traffic at both sites (Appendix F) and plant recovered birds at the pothole transects to estimate carcass scavenging survival (PNR_R). A comparable estimate of carcass scavenging survival for the causeway can be obtained from birds planted and recovered on the highway transect (PNR_C). These data allow adjustment of counts at each area for differing levels of bird activity, vehicle traffic, and scavenging before estimating proportion of birds killed by wire strike at the causeway.

Plantable birds recovered at or between the pothole transects are replanted at pothole transects on paved shoulders of U.S. Highway 83 to estimate PNR_R . Transects are divided into 0.1-mi (0.16-km) segments, with distinctions between east and west shoulders of both northbound and southbound lanes (four possible planting zones in each segment). All possible planting zones are randomly ordered (uniform distribution) and one bird is planted in one or two planting zones three or four days/week.

6

RESULTS OF DEAD-BIRD SEARCHES IN 2001 AND 2002

Setup of search transects at Audubon Causeway and training of Meghan Dinkins to conduct dead-bird searches was accomplished 4–14 April 2001. Identification and marking of highway transects at the reference study site and training of Sheridan Walter were accomplished 4–8 June 2001. Sheridan's responsibilities were to mark and plant dead birds for bias estimation, conduct field necropsies of recovered birds, and take data on rates of low-flying birds crossing highway transects and vehicle traffic at both reference and causeway sites. Dead-bird searches were conducted from 17 April–31 October 2001 (approximately 1200 hr) and bird planting was conducted from 5 June–23 October 2001 (approximately 950 hr, including necropsy and observation time).

In 2002, refurbishment of transects and training of field personnel occurred 8–19 April. Andrea Locke and Wendy Morgan conducted dead-bird searches. Shelagh Tupper coordinated field activities, planted dead birds, and conducted necropsies and highway transect observations. Dead-bird searches occurred 17 April–31 October 2002 (approximately 1950 hr) and bird planting occurred 10 May–28 October 2002 (approximately 1000 hr, including necropsy and observation time).

Observations of Birds Colliding with Wires

Direct observation of avian collisions was not an objective of fieldwork, but several collisions were incidentally documented. In 2001, 4 birds were observed colliding with power line wires. On 29 June, one westbound adult double-crested cormorant hit a middle level conductor at Span 8. The bird struck the wire with its leg and flew on unimpaired. On 27 September, three westbound Franklin's gulls struck either a static wire or one of the highest conductors at Span 9, all within a period of about 3 minutes. None appeared to be injured. On 17 August, a probable collision was heard, characterized as a loud snap, and an adult cormorant was seen to fall into Lake Audubon at Span 6. This bird was not killed upon impact, did not appear stunned in the water, and tried to fly up from the water but was not successful while being observed. Direction of travel and wire level was not known.

In 2002, our crews observed two collisions. On 29 April, one eastbound adult double-crested cormorant hit a middle level conductor at Span 2 and fell into Lake Audubon. It was recovered dead with one broken wing and abrasions on head and base of neck. On 14 May, one eastbound adult ring-billed gull struck its left wing on a static wire at Span 4. This collision occurred in a moderate wind and the bird appeared uninjured. On 15 July, a motorist reported a westbound cormorant struck a wire (unidentified) and fell to the ground at Span 11, but the crew was unable to find the bird.

Dead Birds Found at Audubon Causeway Transects

In 2001, 451 dead birds were recovered at causeway transects (63 species, Table 6-1), and 434 dead birds were recovered in 2002 (77 species, Table 6-2). In both years, passerines and gulls were the largest groups of birds collected (Table 6-3). Although 60 dead terns were collected in 2001 only 5 were collected in 2002. Specifically, more black terns were found in 2001 than any other species, but only one was found in 2002 and they were not commonly observed at the causeway. Coots, ducks, grebes, and shorebirds were also commonly recovered in both years, but many more pheasants were found in 2002 (21) than in 2001 (5). We found no raptors at the causeway in 2001, but found one great horned owl in 2002.

We are interested in quantifying numbers of birds killed in collisions with power line wires, but birds at Audubon Causeway die from other causes, primarily vehicle collisions. We initially screened the raw data to eliminate birds killed by something other than wire strikes. Because pheasants are rarely observed flying at wire height, we assume all pheasants died from some cause other than wire strikes. In late summer 2001, a large number of fish died in Lake Audubon and pelicans recovered during that time period probably died from associated botulism. We eliminated 1 Canada goose that probably died from hunter wounding, 11 pelicans, and 5 pheasants from 2001 data, and 21 pheasants and 2 ducklings from 2002 data. Our primary data set is comprised of the remaining birds (434 in 2001 and 411 in 2002) likely killed by collisions with either power line wires or vehicles.

Temporal and spatial patterns in the raw data are shown in Figure 6-1 and Figure 6-2, respectively. Birds found in the lower 3 ft (0.91 m) of riprap above Lake Audubon and at beaches were excluded from span-specific data sets (Figure 6-2). Although a few of these birds may have been killed away from the causeway, we reason that less bias results from including such birds in the overall data set (Figure 6-1) than from excluding them. However, we expect a high proportion of birds that wash up from Lake Audubon were killed at a different span, thus we censor them from span-specific data. Also, we assumed that birds found within 50 ft (15.2 m) of span end boundaries may have been killed in either span and removed them from span-specific data tabulations and analyses. Sample sizes were 363 and 339 in span-specific data sets for 2001 and 2002, respectively.

Table 6-1
Dead Birds found at Audubon Causeway (Total=451), 17 April–31 October 2001

Number of Birds	Species	Number of Birds	Species
46	Black Tern	2	Blackbird sp.
42	American Coot	2	Brown-headed Cowbird
36	Ring-billed Gull	2	Clay-colored Sparrow
23	Franklin's Gull	2	Green-winged Teal
19	California Gull	2	Killdeer
17	Gull sp.	2	Purple Martin
14	Double-crested Cormorant	2	Song Sparrow
14	Western Grebe	2	Spotted Towhee
12	American White Pelican	2	Tern sp.
11	Eared Grebe	2	Western Meadowlark
10	Bank Swallow	1	American Redstart
10	Pied-billed Grebe	1	American Wigeon
8	Mourning Dove	1	Baltimore Oriole
8	Yellow-headed Blackbird	1	Blue-winged Teal
7	Forster's Tern	1	Bobolink
7	Sora	1	Brown Thrasher
7	Sparrow sp.	1	Bufflehead
7	Swallow sp.	1	Canada Goose
6	Common Grackle	1	Cedar Waxwing
6	Gadwall	1	Common Loon
6	Passerine sp.	1	Dowitcher sp.
6	Savannah Sparrow	1	Great Blue Heron
5	Cliff Swallow	1	Harris's Sparrow
5	Common Tern	1	Lapland Longspur
5	House Sparrow	1	Lesser Scaup
5	Marbled Godwit	1	Lesser Yellowlegs
5	Ring-necked Pheasant	1	Red-winged Blackbird
5	Ruddy Duck	1	Sabine's Gull
4	Piping Plover	1	Sandpiper sp.
3	Common Yellowthroat	1	Warbler sp.
3	Mallard	1	Western Kingbird
3	Sanderling	1	Wilson's Phalarope
3	Semipalmated Sandpiper	1	Wood Duck
3	Spotted Sandpiper	1	Yellow-breasted Chat
2	American Goldfinch	1	Yellow-rumped Warbler
2	Black-bellied Plover	31	Unknown

Table 6-2
Dead Birds found at Audubon Causeway (Total=434), 17 April–31 October 2002

Number of Birds	Species	Number of Birds	Species
46	Ring-billed Gull	2	Sanderling
31	Gull sp.	2	Swamp sparrow
24	American Coot	2	Tern sp.
21	Ring-necked Pheasant	2	Warbler sp.
19	Double-crested Cormorant	2	Western Sandpiper
17	Franklin's Gull	2	Yellow Warbler
11	Sparrow sp.	1	American Redstart
10	Mourning Dove	1	American Robin
10	Savannah Sparrow	1	American White Pelican
10	Western Grebe	1	Blackbird sp.
7	Mallard	1	Blackburnian Warbler
7	Sora	1	Black Tern
6	Eastern Kingbird	1	Bobolink
5	Brewer's Blackbird	1	Bufflehead
5	Brown-headed Cowbird	1	Catbird
5	Cliff Swallow	1	Canada Goose
5	Eared Grebe	1	Clay-colored Sparrow
5	Swallow sp.	1	Common Loon
5	Yellow-headed Blackbird	1	Field Sparrow
4	American Tree Sparrow	1	Gray Catbird
4	Bank Swallow	1	Great Horned Owl
4	Common Grackle	1	Grebe sp.
4	Gadwall	1	Harris's Sparrow
4	Horned Grebe	1	House Sparrow
4	Killdeer	1	Lesser Yellowlegs
3	California Gull	1	Northern Pintail
3	Duck sp.	1	Purple Finch
3	Grasshopper sparrow	1	Red-eyed Vireo
3	Lincoln's Sparrow	1	Red-winged Blackbird
3	Nelson's Sharp-tailed sparrow	1	Rock Dove
3	Pied-billed Grebe	1	Ruddy Duck
3	Piping Plover	1	Semipalmated Sandpiper
3	Red-necked Phalarope	1	Shorebird sp.
3	Tennessee Warbler	1	Stilt Sandpiper
2	Baird's Sparrow	1	Song Sparrow
2	Barn Swallow	1	Upland Sandpiper
2	Blue-winged Teal	1	Vesper Sparrow
2	Brown Thrasher	1	Virginia Rail
2	Common Tern	1	Warbling Vireo
2	Common Yellowthroat	1	Western Meadowlark
2	Green-winged Teal	1	Wren sp.
2	Horned Lark	1	Yellow-breasted Chat
2	Marbled Godwit	1	Yellow-rumped Warbler
2	Nashville Warbler	65	Unknown

Table 6-3
Most Common Species Groups (>20 individuals) found at Audubon Causeway, 2001 and 2002

2001		2002	
Number of Birds	**Species Group**	**Number of Birds**	**Species Group**
96	Gull	114	Passerine
92	Passerine	97	Gull
60	Tern	24	Coot
42	Coot	22	Grebe
35	Grebe	21	Duck
26	Shorebird	21	Pheasant
21	Duck	21	Shorebird

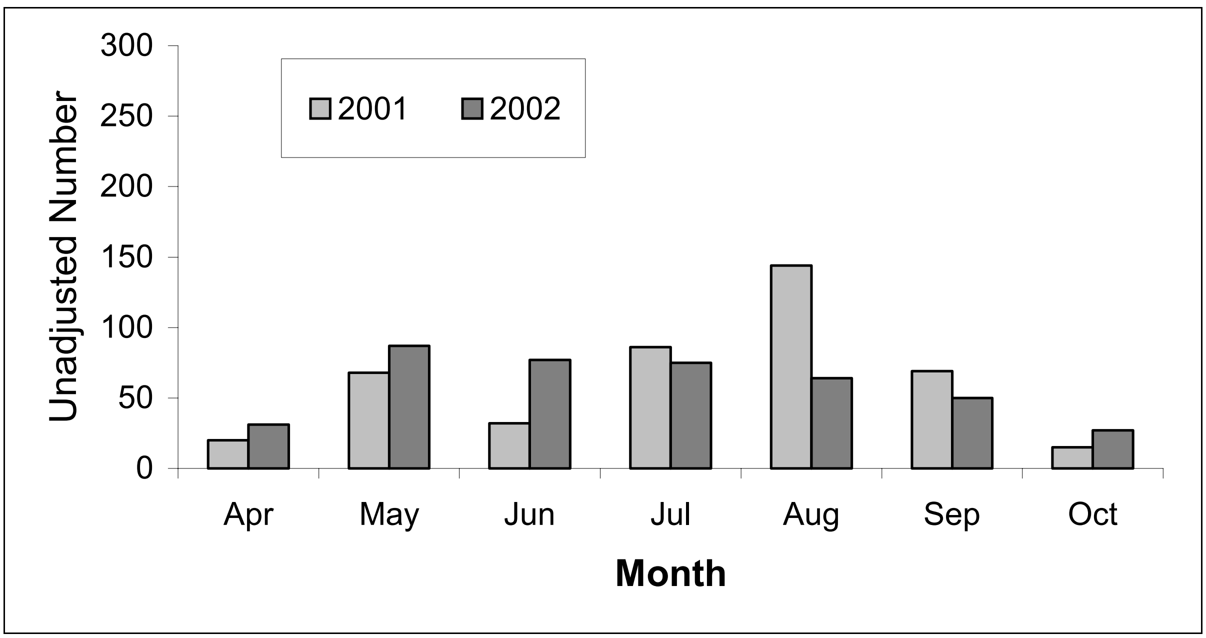

Figure 6-1
Temporal Patterns in Numbers of Dead Birds Collected at Survey Transects at Audubon Causeway Without Adjustment for Recovery Rates

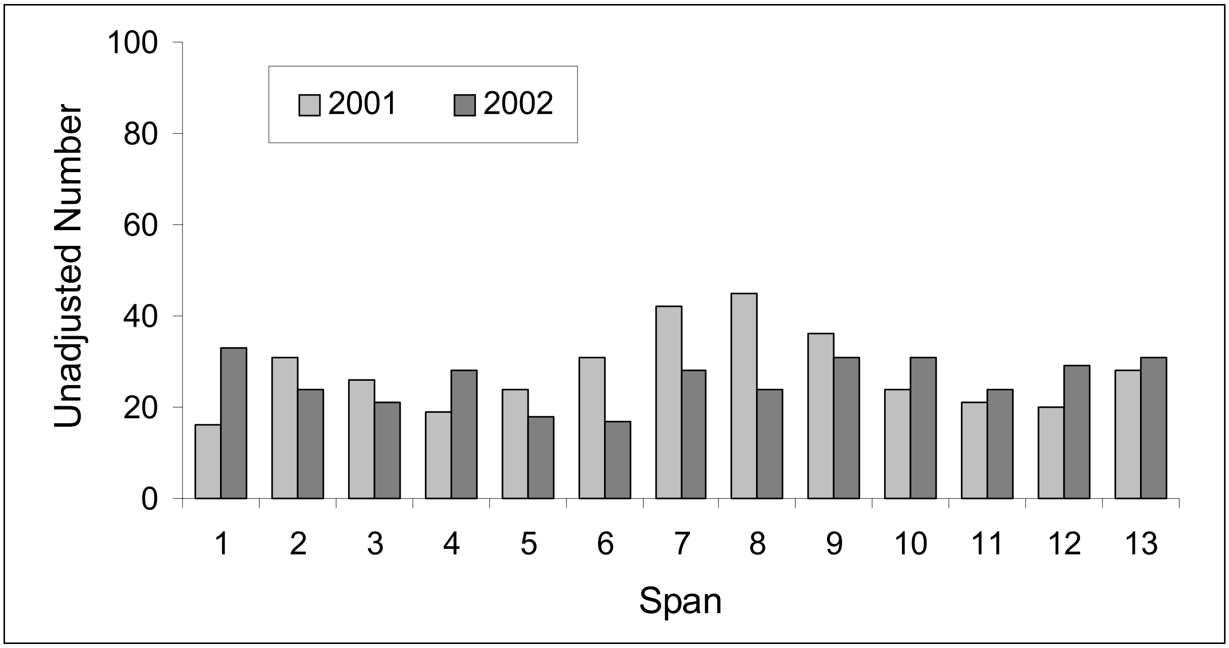

Figure 6-2
Spatial Patterns in Numbers of Dead Birds Collected at Survey Transects at Audubon Causeway without Adjustment for Recovery Rates

Dead-Bird Recovery Rate Estimation

Birds Placed at Audubon Causeway

Date, number/day, location, and bird were randomly generated for marked dead birds placed at search transects at Audubon Causeway. Total sample sizes were 146 in 2001 and 208 in 2002. Approximately equal within-year sample sizes were maintained among spans, except Spans 1 and 13 had more planted birds than other spans (Table 6-4).

Table 6-4
Spatial Distribution of Birds Placed at Audubon Causeway for Estimating Recovery Rates

Year	Span													Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	
2001	17	10	9	10	11	11	11	11	10	9	9	11	17	146
2002	27	14	15	13	13	14	13	14	13	14	14	15	29	208

Randomized selection of birds and planting locations produced a reasonably well-distributed sample among bird length and habitat-related visibility class of planting locations, but very large and very small birds may not have been optimally represented (Table 6-5). Size classifications in Table 6-5 are arbitrary, and different classifications would show different patterns. These classifications were not used in modeling recovery rates, only for convenience in presenting data. Birds available for planting ranged from 4.75 in (12.1 cm) to 62 in (157.5 cm).

Table 6-5
Numbers of Birds Placed at Audubon Causeway for Estimating Recovery Rates. Classification of Bird Length shown here is Convenient for Summarization – Bird Length was treated as a Continuous Variable in Logistic Regression

Visibility Class	Bird Length (in)					Total
	≤6	>6 – 10	>10 – 15	>15 – 20	>20	
High	22	45	40	44	22	173
Low	24	39	47	49	22	181
Total	46	84	87	93	44	354

Model Selection

There is little support for models representing simple pooled estimates of recovery rate for both years combined (“intercept only” model, Table 6-6), a single estimate for each year (*year* model), a single estimate for each span (*span* model), or estimates for each span in each year (*year*, *span* model). The AIC best approximating model for recovery rate is a relatively simple function of bird length and habitat-related visibility class:

$$\text{logit}(\hat{r}_i) = -3.4200 + 0.2544\times \text{blen}_i + 1.3265\times \text{vis}_i \ .$$

Although there is greater support for the *blen*, *vis* model ($w_1 = 0.186$) than for the next lower model (*blen*, *vis, blen*×*vis*; $w_2 = 0.123$), the *blen*, *vis* model is not overwhelmingly superior, and several of the next highest models have worthwhile weight of evidence for inclusion in estimation. We selected the top five models for further evaluation because they ranged up to about $\Delta_l = 2$ and included potentially useful additional effects for *tvis*, *year*, and *stype* (Table 6-7). The *blen*, *dends*, *vis* model would also have been interesting, but it is redundant to the *blen*, *vis* model (the coefficient of the *dends* term in most models is zero). We conclude there is no evidence that recovery rates (logit scale) varied as a linear function of distance from causeway ends.

Table 6-6
Logistic Regression Models Considered for Estimating Recovery Rate, Ranked by AIC$_c$

Model	Number of Parameters	Log Likelihood	AIC$_c$	Δ_I	Akaike Weight
1: *blen, vis*	3	-175.619	357.31	0.00	0.186
2: *blen, vis, blen*vis*	4	-175.011	358.14	0.83	0.123
3: *blen, tvis*	5	-174.048	358.27	0.96	0.115
4: *year, blen, vis*	4	-175.463	359.04	1.73	0.078
5: *stype, blen, vis*	4	-175.5601	359.23	1.93	0.071
blen, dends, vis	4	-175.616	359.35	2.04	0.067
*year, blen, vis, blen*vis*	5	-174.829	359.83	2.52	0.053
year, blen, tvis	6	-173.8149	359.87	2.57	0.052
*stype, blen, vis, blen*vis*	5	-174.9478	360.07	2.76	0.047
*blen, dends, vis, blen*vis*	5	-175.004	360.18	2.87	0.044
dends, blen, tvis	6	-174.0332	360.31	3.00	0.042
year, stype, blen, vis	5	-175.4142	361.00	3.69	0.029
year, blen, dends, vis	5	-175.458	361.09	3.78	0.028
*year, dends,blen,vis, blen*vis*	6	-174.8182	361.88	4.57	0.019
year, dends, blen, tvis	7	-173.7956	361.91	4.61	0.019
*blen, tvis, blen*tvis*	8	-173.0469	362.51	5.20	0.014
*year, blen, tvis, blen*tvis*	9	-172.7548	364.03	6.73	0.006
*dends, blen, tvis, blen*vis*	9	-173.0335	364.59	7.28	0.005
*year, dends, blen, tvis, blen*tvis*	10	-172.7358	366.11	8.81	0.002
blen	2	-188.340	380.71	23.41	<0.001
stype, blen	3	-187.5762	381.22	23.91	<0.001
stype, blen	3	-187.5762	381.22	23.91	<0.001
blen, dends	3	-187.747	381.56	24.26	<0.001
year, blen	3	-188.211	382.49	25.18	<0.001
year, stype, blen	4	-187.4289	382.97	25.67	<0.001
*year, span, tvis, dends, blen, blen*tvis*	22	-168.2553	383.57	26.26	<0.001
vis	2	-230.341	464.72	107.41	<0.001
year, vis	3	-229.805	465.68	108.37	<0.001
dends, vis	3	-230.076	466.22	108.91	<0.001
stype, vis	3	-230.3028	466.67	109.37	<0.001
stype, vis	3	-230.3028	466.67	109.37	<0.001
year, stype, vis	4	-229.7755	467.67	110.36	<0.001
dends	2	-237.645	479.32	122.02	<0.001
intercept only	1	-238.802	479.62	122.31	<0.001
year, dends	3	-237.197	480.46	123.16	<0.001
stype	2	-238.3939	480.82	123.52	<0.001
year	2	-238.411	480.86	123.55	<0.001
stype, dends	3	-237.6405	481.35	124.04	<0.001
year, stype	3	-237.9674	482.00	124.70	<0.001
year, stype	3	-237.9674	482.00	124.70	<0.001
span	13	-235.1192	497.31	140.00	<0.001
year, span	14	-234.6315	498.50	141.20	<0.001

Table 6-7
Specification of Top Five Candidate Models. Coefficients are on Logit Scale

Term	Model				
	Blen vis	***Blen vis blen ×vis***	***Blen tvis***	***Year blen vis***	***Blen vis stype***
intercept	-3.4200	-3.0330	-3.4821	-3.3499	-3.4621
blen	0.2544	0.2246	0.2561	0.2536	0.2544
tvis (high)	–	–	1.4060	–	–
tvis (meadow)	–	–	0.0621	–	–
tvis (riprap)	–	–	0	–	–
tvis (railway-ditch)	–	–	-0.0913	–	–
vis (high)	1.3265	0.5176	–	1.3284	1.3566
vis (low)	0	0	–	0	0
blen×*vis* (=*blen* if *vis*=high)	–	0.0709	–	–	–
year (2001)	–	–	–	-0.1480	–
year (2002)	–	–	–	0	–
stype (end)	–	–	–	–	0.1071
stype (interior)	–	–	–	–	0

Recovery rates back transformed from the *blen*, *vis* model provide curves (Figure 6-3) for high and low visibility locations beginning at relatively low values for small birds and converging asymptotically to nearly 1.0 for birds longer than about 30 in (762 mm). These curves seem logical. Small birds in low visibility habitat conditions are difficult to detect, even at close range, and in high visibility areas they can be easily located and removed by scavengers. Large birds are easier to detect by humans, regardless of habitat, and more difficult for scavengers to remove intact.

Simple proportions of planted birds recovered (and confidence intervals) were calculated for groups shown in Table 6-5 and compared with recovery rates from the *blen*, *vis* model in Figure 6-4 [95% CI = $r \pm \mathrm{se}(r)\, t_{0.025,\mathrm{n-1}}$ and $\mathrm{se}(r) = \sqrt{r(1-r)/n}$]. Although this model appears to overestimate recovery rates for very small birds at high visibility locations and very large birds at all locations, confidence intervals for large-bird recovery rates include model recovery rates, so differences for large birds may result from small sample sizes. Disparity between model and group estimate for small birds at high visibility locations more likely represents some lack of model fit. Greater uncertainty exists for the tails of the fitted models because of relatively small samples for very small and very large birds.

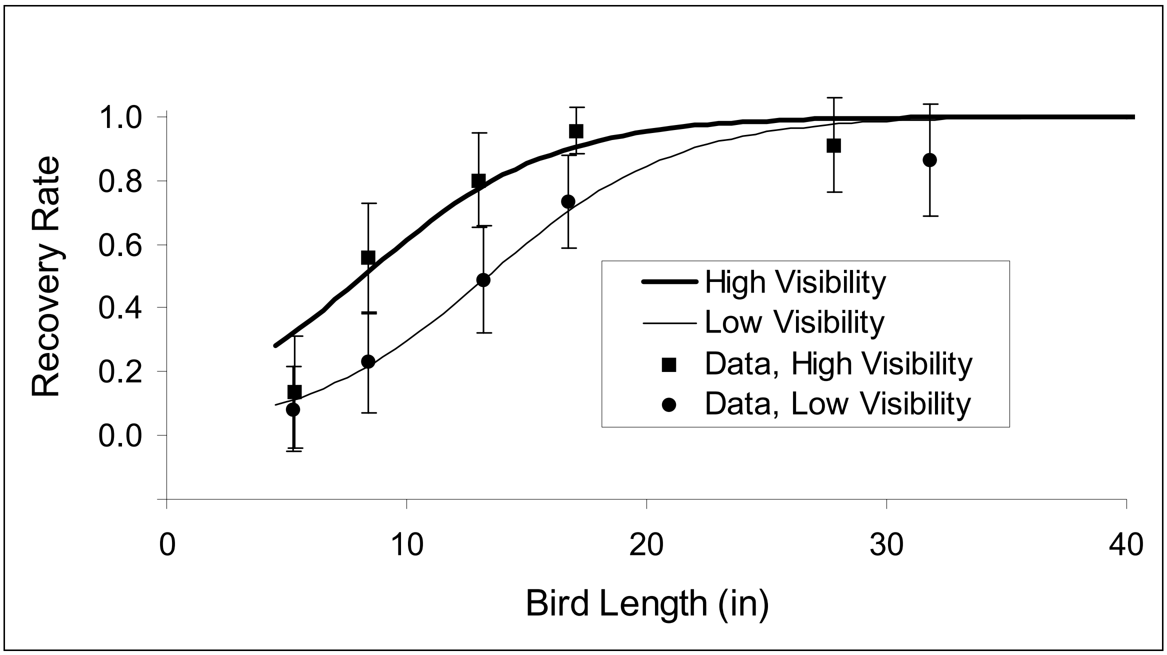

Figure 6-3
Relationship Between Bird Length and Recovery Rate for High and Low Habitat-Related Visibility Classifications Based on Model 1 (*blen*, *vis*), and Proportion of Planted Birds Recovered with 95% Confidence Intervals Based on Data Grouped According to Table 6-5

The *blen*, *vis*, *blen*×*vis* model is interesting because it agrees somewhat better with the data for small birds in high visibility areas (Figure 6-4). The *blen*, *tvis* model exhibits very little difference in effect for each low-visibility transect type when modeled separately (Table 6-5). The *blen*, *vis* model provides essentially the same results with only two visibility classes. The remaining models exhibit relatively small influences from year (Figure 6-6) and span type (Figure 6-7). Models 3–5 are essentially redundant to the *blen*, *vis* model because effects of *tvis*, *year*, and *stype* are so small. Although we have a priori reasons to expect effects for these additional variables, their inclusion in estimation does not appear warranted for this data set.

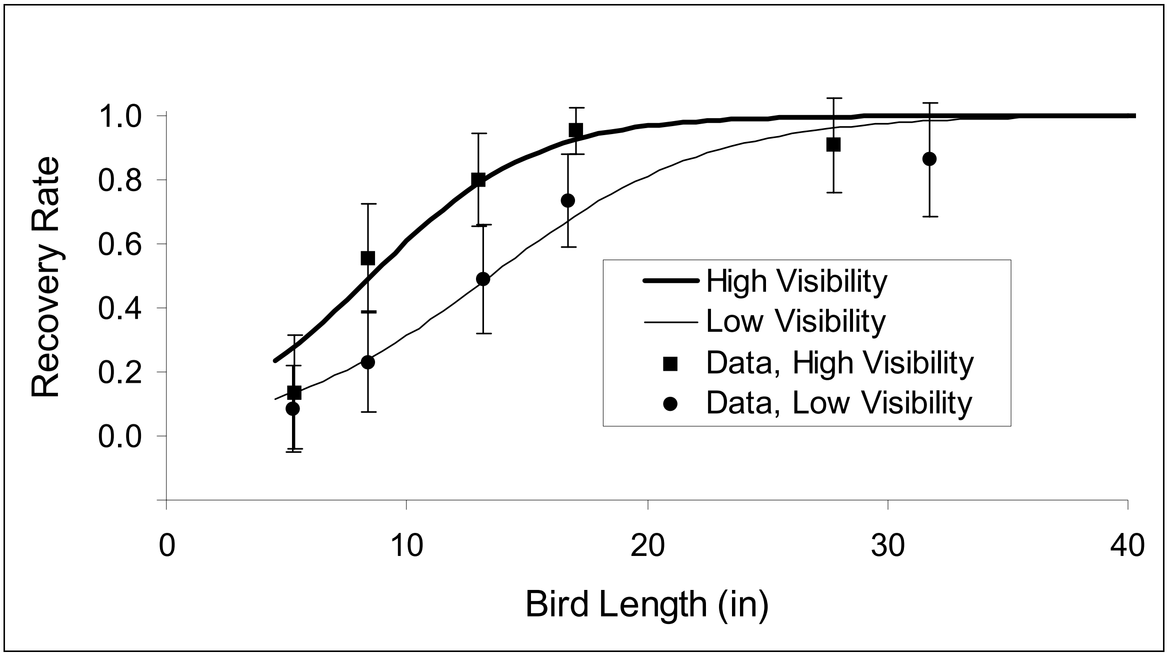

Figure 6-4
Relationship Between Bird Length and Recovery Rate for High and Low Habitat-Related Visibility Classifications Based on Model 2 (*blen*, *vis*, *blen*×*vis*), and Proportion of Planted Birds Recovered with 95% Confidence Intervals Based on Data Grouped According to Table 6-5

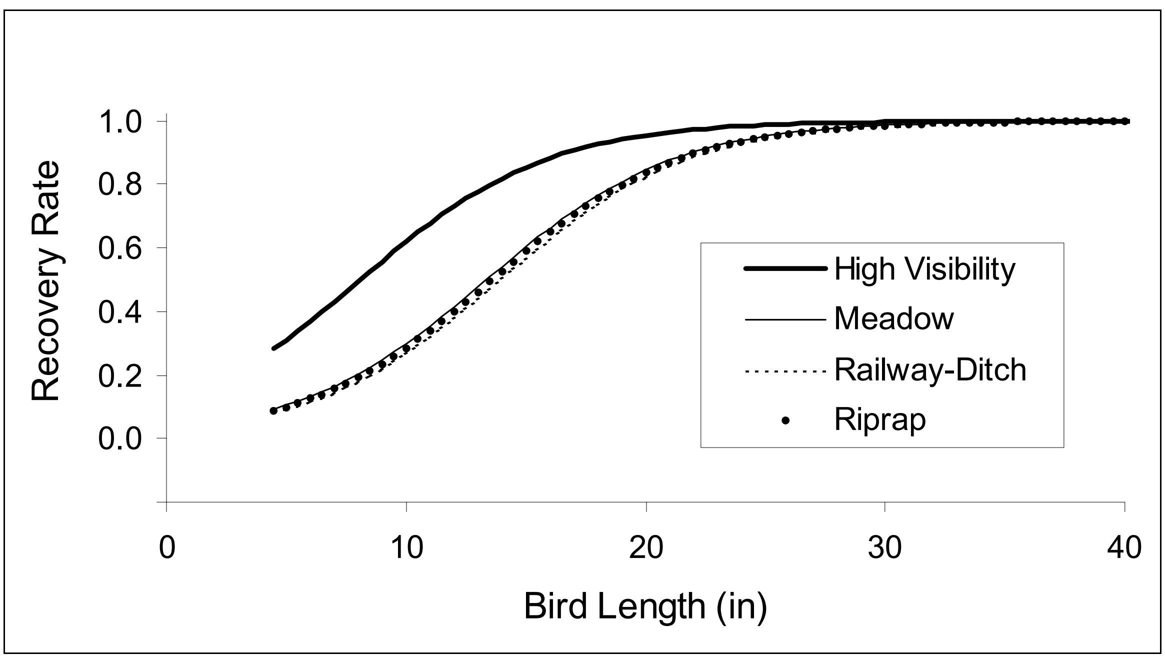

Figure 6-5
Relationship Between Bird Length and Recovery Rate for Habitat-Related Visibility Classifications Based on Model 3 (*blen, tvis*)

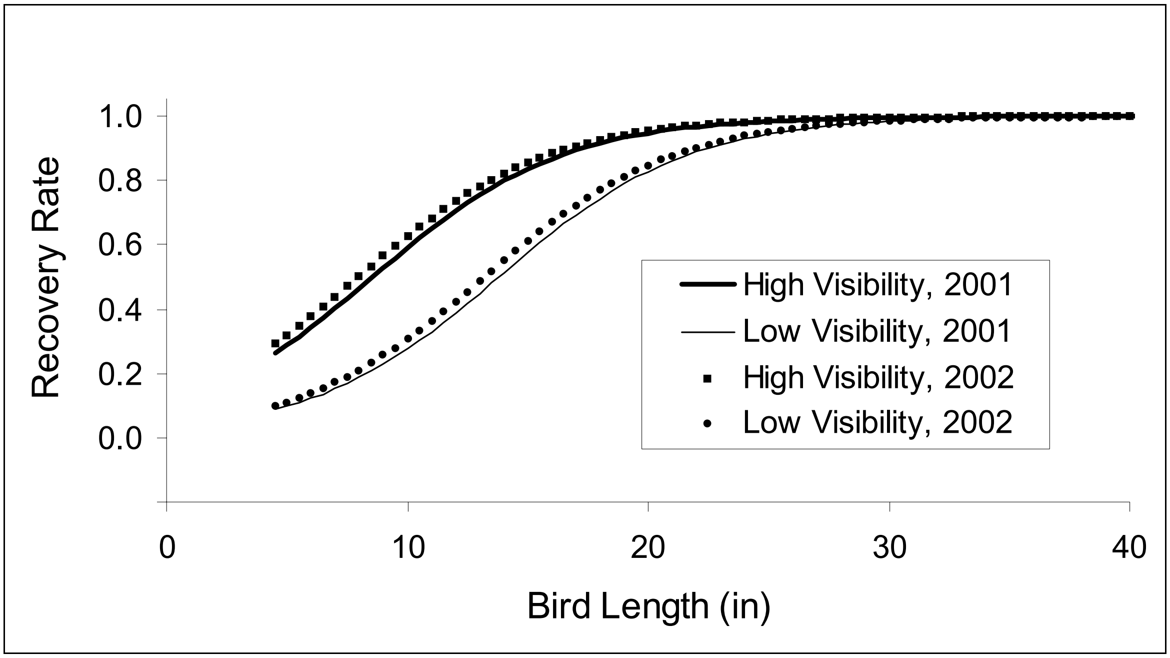

Figure 6-6
Relationship Between Bird Length and Recovery Rate for High and Low Habitat-Related Visibility Classifications by Year Based on Model 4 (year, *blen, vis*)

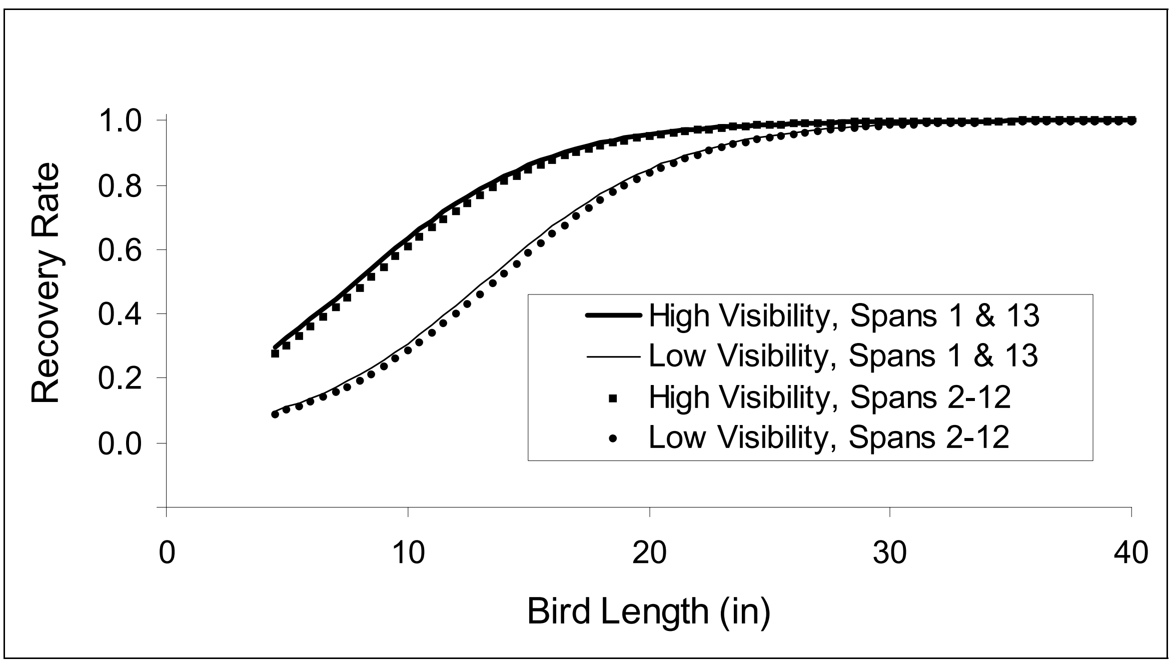

Figure 6-7
Relationship Between Bird Length and Recovery Rate for High and Low Habitat-Related Visibility Classifications by Span Type Based on Model 5 (stype, *blen, vis*)

Recovery Rates

We used the *blen*, *vis* and *blen*, *vis*, *blen*×*vis* models to estimate recovery rates with Akaike weights calculated for the two-model set (w_1 = 0.602 and w_2 = 0.398). Because bird length was included in final models, we used Equation 5-16 rather than Equation 5-7 for adjusting counts in this data set. We assumed r = 0.596 (overall mean recovery rate for both years) for birds of unknown species.

We estimate that 839 (unadjusted count = 434) and 900 (unadjusted count = 411) dead birds occurred inside search areas at Audubon Causeway in 2001 and 2002, respectively. These estimates should be interpreted as numbers of dead birds occurring within search transects during each respective field season. They are not estimates of total numbers of collisions or total numbers of fatalities. Estimated numbers of dead birds are shown by month (Table 6-8) and span (Table 6-9) for 2001 and 2002. Bird length is the dominant predictor variable. The "value" of each bird is increased by a factor of $1/\hat{r}_j$, which is always ≥1, so every bird is "valued" ≥1. The smaller the bird the greater the value of each one found. It follows that any large relative increases in span- or month-specific estimates of dead birds, compared to unadjusted counts, relate mostly to greater numbers of small birds found. Although some spans had similar numbers of dead birds in each year, other spans appeared to vary considerably. Span-specific estimates constitute the primary data set for designing the wire marking study and for BSI deployment planning.

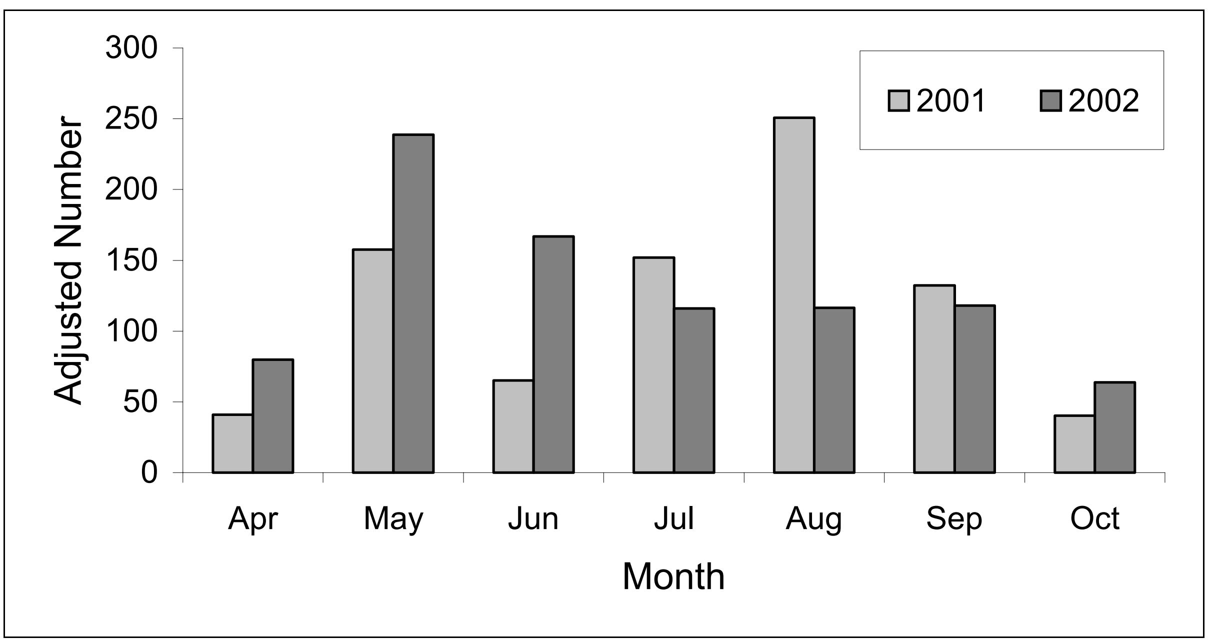

Figure 6-8
Temporal Distribution of Estimated Numbers of Dead Birds Occurring within Search Transects at Audubon Causeway, Based on Averaging Models 1 and 2

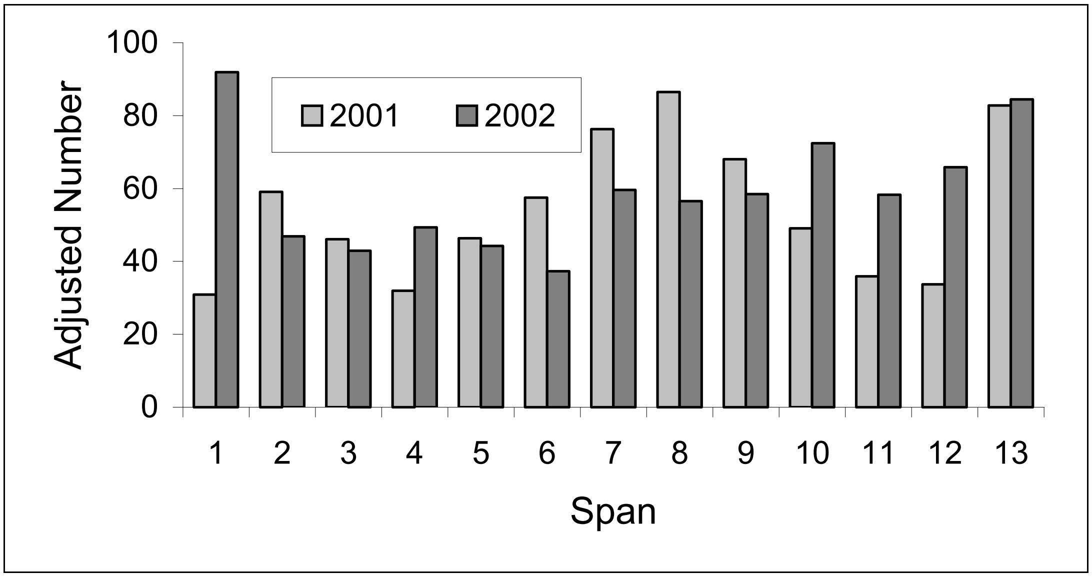

Figure 6-9
Spatial Distribution of Estimated Numbers of Dead Birds Occurring within Search Transects at Audubon Causeway, Based on Averaging Models 1 and 2

Caution is advised in interpreting Figure 6-8 and Figure 6-9 because confidence intervals are not yet available for these estimates. Variance estimators will require inclusion of covariances to account for correlation among modeled recovery rates. Averaging multiple models will complicate variance estimation, perhaps beyond practical limits of time and effort, so final estimates may be based on the AIC best model. Only minor differences in estimates of dead birds result. For example, the *blen*×*vis* model estimates 842 and 909 dead birds for 2001 and 2002, respectively, and Figure 6-10 shows span-specific estimates that are similar to Figure 6-9.

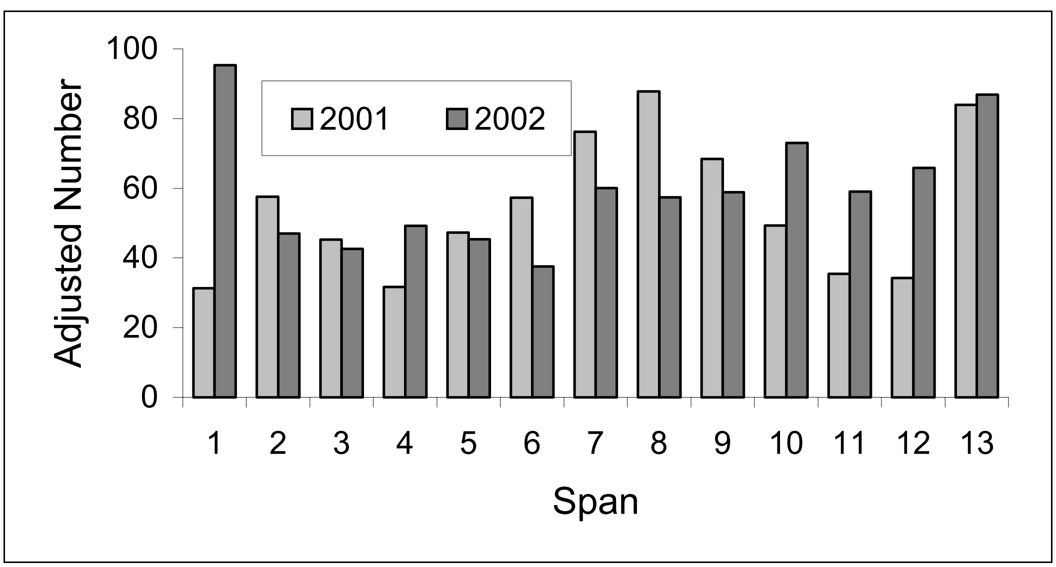

Figure 6-10
Spatial Distribution of Estimated Numbers of Dead Birds Occurring within Search Transects at Audubon Causeway, Based on Model 1, only (*blen*×*vis* model)

Relative Bias of Estimators

Lower estimates of dead birds would have resulted if simple estimates of recovery rate (without considering effects of bird size and habitat related visibility) were used to adjust count data. For example, the *year* model gives $\hat{r}_{2001}$ = 0.568 and the simple estimator of dead birds is $\hat{N}_{2001}$ = 434/0.568 = 764. Similarly, for 2002, $\hat{r}_{2002}$ = 0.615 and $\hat{N}_{2002}$ = 411/0.615 = 668. Estimates based on simple group mean recovery rates will be biased when recovery rate varies by species and the true numbers of dead birds are distributed (with respect to factors causing variation in recovery rates) differently between the overall population of dead birds and the sample used to estimate recovery rates.

We explored the behavior of Equation 5-7 and Equation 5-16 for cases when truth was known concerning true probability of recovery (r_s) and for three hypothetical species of known number (N_s) within a population of N = 300. We assumed a sample of n = 300 planted birds equally distributed among species with identical recovery rates as the population and no sampling variance. Numbers of recovered planted birds were used to estimate a pooled recovery rate ($\overline{r}$) for the population. Equation 5-7 was used with total number of birds found (not replants) and $\overline{r}$ to estimate the total population. Equation 5-16 was used with the appropriate value of r_s to estimate the total population. Although Equation 5-7 ignored species effects in estimating population size, it performed well when actual numbers of dead birds were distributed among species like the planted bird sample (uniformly), but poorly when relatively more large or small birds (high and low recovery probabilities, respectively) were present (Table 6-8). Evaluations of additional cases where planted-bird samples were not uniformly distributed among species indicate that Equation 5-7 performs well only when bird distributions are similar in the full population of dead birds and in the planted-bird sample. Equation 5-16 was unbiased in all cases we evaluated.

Table 6-8
Biases of Estimated Population Sizes from Equation 5-7 and Equation 5-16 (True Total *N* = 300) for Three Hypothetical Species with Different Probabilities of Recovery (r_s) and Numbers/Species (N_s) and Sampling Variance in Estimating r_s is Ignored

Case	Species						Bias (%)	
	1		2		3		Equation 5-7	Equation 5-16
	r_1	N_1	r_2	N_2	r_3	N_3		
1	0.4	50	0.3	100	0.2	150	-11	0
2	0.4	100	0.3	100	0.2	100	0	0
3	0.4	150	0.3	100	0.2	50	11	0
4	0.9	50	0.5	100	0.1	150	-27	0
5	0.9	100	0.5	100	0.1	100	0	0
6	0.9	150	0.5	100	0.1	50	27	0
7	0.9	50	0.8	100	0.7	150	-4	0
8	0.9	100	0.8	100	0.7	100	0	0
9	0.9	150	0.8	100	0.7	50	4	0

Estimators can perform differently when effects of sampling are included. We conducted simulations of 5000 replicate "studies" for each case shown in Table 6-8 to explore the behavior of Equation 5-7 and Equation 5-16. Recovery rates were not fixed within species, but varied randomly for each "study" based on random binomial variates with probability r_s and sample size = 100/species. Adjusted counts for each "study" were obtained using species-specific recovery rates with Equation 5-16, and a species-averaged recovery rate with Equation 5-7. Mean bias was calculated for Equation 5-7 and Equation 5-16 for each case.

Introducing sampling variance to recovery rate estimation minimally influenced biases associated with Equation 5-7 (Table 6-9). Sampling variation introduced small biases into estimates from Equation 5-16 but this estimator remained more consistent than Equation 5-7. Also, the Equation 5-16 estimator appears to be asymptotically unbiased (bias decreases to zero as sample size used to estimate recovery rates increases) based on additional simulations with increasingly larger samples of planted birds.

Table 6-9
Biases of Estimated Population Sizes from Equation 5-7 and Equation 5-16 (True Total N = 300) for Three Hypothetical Species with Different Probabilities of Recovery (r_s) and Numbers/Species (N_s), where Numbers of Planted Birds Recovered/Species is a Random Binomial Variate (for r_s, N_s)

Case	Species						Bias (%)	
	1		2		3		Equation 5-7	Equation 5-16
	r_1	N_1	r_2	N_2	r_3	N_3		
1	0.4	50	0.3	100	0.2	150	-10	3
2	0.4	100	0.3	100	0.2	100	1	3
3	0.4	150	0.3	100	0.2	50	12	2
4	0.9	50	0.5	100	0.1	150	-27	6
5	0.9	100	0.5	100	0.1	100	<1	4
6	0.9	150	0.5	100	0.1	50	27	2
7	0.9	50	0.8	100	0.7	150	-4	<1
8	0.9	100	0.8	100	0.7	100	<1	<1
9	0.9	150	0.8	100	0.7	50	4	<1

Bias levels illustrated in this simple example are probably not equivalent to what we might expect given our data set. They are provided for relative evaluation of estimators, only. We conclude that Equation 5-16 is more appropriate for this study because the distribution of bird sizes in the planted sample is more likely similar to that of dead birds originally recovered at the causeway, not to the full population of dead birds that occurred there. Under those conditions, Equation 5-16 is likely less biased than Equation 5-7. Importantly, biases that result from Equation 5-16 will decline as the data set used to model recovery rate increases with additional years of bird searches, but biases from Equation 5-7 will not.

Future Work

We expect that vehicle collisions and power line wire strikes are the predominant cause of fatalities at causeway search areas, but have not yet evaluated data to discriminate between these factors. Future work will include evaluating 187 and 215 necropsies (from 2001 and 2002, respectively), refining discrimination criteria between wire and vehicle strikes, and testing discrimination criteria for consistency among independent evaluators. Dead bird, vehicle, and bird over-flight counts from highway transects at causeway and reference sites will also be evaluated to discriminate between vehicle and wire collision. One, or both, of these approaches will be used to estimate the proportion of dead birds attributable to wire strike.

Additional future work will include development and verification of variance estimators for adjusted counts based on Equation 5-16 and for total variance of adjusted counts when more than one probability is used in Equation 5-7. These variance estimators, along with year- and span-specific estimates of dead birds and estimates of proportion of birds killed by wire strike will enable simulations necessary for developing a wire marking experimental design. We will consider relative frequencies of bird species (or groups) among estimates of dead-bird numbers, relative frequencies of fatalities occurring during daylight and darkness (or low light), and effects of weather covariates, when selecting a wire marking product and deployment plan. Similarly, we will develop a deployment plan for BSI units based on available data from bird searches.

The dead bird planting data set will grow with additional years of field surveys. Additional years of data will require analysis of the entire data set, thus models for recovery rates will not be finalized until the marking study is completed. Results presented in Figure 6-8, Figure 6-9, and Figure 6-10 are interim in nature because they will change slightly as recovery rate models change through time.

7
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A
BSI FUNCTIONAL SPECIFICATION

The Bird Strike Indicator (BSI) is an impulse-based vibration sensing and recording tool to monitor bird strikes on aerial cables. The premise for the BSI is that avian collisions with aerial cables will produce vibration in the cables that can be monitored to provide information on avian interaction with the cables.

The goal for the design and development of the BSI is to produce a sensor that can be easily installed on aerial cables to monitor and record vibrations above a certain preset threshold. The sensor should include filtering capabilities to allow filtering of unwanted noise due to wind induced low frequency vibration. The cut off frequency parameters for the filter will need to be adjusted as more data are gathered and more is learned about the characteristics of the vibrations caused by bird strikes. The BSI sensors mounted on the cables will report information on bird strikes to a base station from which the information can be remotely downloaded using a variety of communication options. The base station could be located on a tower, a nearby structure or a building.

These Functional Specifications provide general information on a variety of parameters to frame the Bird Strike Indicator (BSI) system R&D. These specifications are not intended to provide the detailed information that might be typical of a final system design. The specifications are divided into the following categories:

- Operational Specifications
- Physical Specifications
- Environmental Specifications
- Electrical Power Specifications
- Communications Specifications

Operational Specifications

BSI sensor parameters • Threshold • Number of data points • Sampling rate • Filter frequency • Gain • Others	System shall have the capability to enable remote modification of sensor measurement parameters. Band pass digital filters with preset cut of frequencies will be used to eliminate unwanted vibration data. Changes in filter cut off frequencies might require uploading of new filter parameters.
Data transmission options	Sensor shall immediately transmit vibration data that exceed the preset threshold value to the base station. In the event base station is busy communicating with other sensors, the sensor shall transmit the data as soon as communication channels to the base station become available
System reboot/reset	System shall have the capability to automatically reboot in the event of a transient operational anomaly and to be remotely or locally rebooted/reset on command.
System health monitoring	System shall report its health, e.g. date and time, battery voltage, etc., once every day.

Physical Specifications

BSI sensor weight	The goal is to keep the BSI sensor weight to less than 5 lbs. Most of the weight will be due to the battery and the mounting hardware. Effort will be made to optimize the weight of the unit.
Installation	Must be capable of being installed on a live line with hot-sticks.
BSI sensor mount	Mounting hardware shall easily adapt to different conductor sizes.

Environmental Specifications

Operating temperature range	
• Sensor in contact with the conductor • Other electronics	-40ºF to 257ºF (-40º to 125ºC) -40ºF to 176ºF (-40ºC to 80ºC)
Storage temperature range • Sensor in contact with the conductor • Other electronics	-58ºF to 257ºF (-50º to 125ºC) -40ºF to 185ºF (-40ºC to 85ºC)
Operational weather conditions	• Operate in rain and snow • Operate in winds up to 40 mph • Withstand winds up to 115 mph
Operational vibration conditions	Normal low amplitude wind induced line vibration
Operational electromagnetic field	Shall operate in electromagnetic steady state and transient fields produced by power lines operating at system voltages up to 550 kV.

Electrical Power Specifications

BSI sensor mounted on aerial cables	BSI sensor shall be battery powered. Power consumption shall be optimized to ensure sensor operation for at least six months and possibly one year (depending on the quantity of bird strikes) prior to requiring battery replacement.
Base station	The base station shall be capable of being powered using either of the following: • Connection to an AC power source • Solar cells
Optimization of sensor power demands	Sensor shall incorporate a “sleep mode” feature between measurements. The system will remain in sleep mode in between measurements of bird strikes except when reporting its health.

Communication Specifications

Remote communication with base station	Several means for remote communication with the base station shall be enabled and/or investigated including: • Telephone and cellular phone • Satellite (Satellite communication option will be explored but no equipment will be purchased.) • Spread spectrum radio frequency (RF) • Internet
BSI sensor to base station	• Sensor shall communicate with the base station using a frequency hopping spread spectrum radio with a range of 1 mile. • Multiple BSI sensors shall be able to communicate with one base station, one at a time.

B
LIST OF TAG MEMBERS

John Bridges	Western Area Power Administration (Western) – Chairman
Ted Anderson	Western
Dirk Shulund	Western
Steve Rock	Western
Dennis Rankin	USDA Rural Utilities Service
Bradley Blackwell	USDA Wildlife Services
Dick Anderson	California Energy Commission (CEC)
Linda Spiegel	(CEC)
Andy Stewart	EDM International Inc. (EDM)
Rick Harness	EDM
Arun Pandey	EDM
Greg Phillips	EDM
Avain Power Line Interaction Committee (APLIC)	
Monte Garrett	PacificCorps
Sam Milodragovich	Northwestern Power
Tim Chervick	TRC Solutions
Rick Carlton	EPRI
Natalie Sunderman	Idaho Power
Shiela Byrne	Pacific Gas & Electric (PG&E)
Al Manville	U.S. Fish and Wildlife Service (Service)
Cyndi Perry	Service

Leo Suazo	Service
Paul Schmidt	Service
Pete Smith	Service
Rich Grosz	Service
Michael Crowder	Purdue University
Jo Hess	Tasmania Hydro
J. Jose Gonzalez	Red Electrica (REE)
Jorge Roig Soles	REE
Karl Myers	Tri-State G & T
Shiela Frazier	ECG Inc.
Andrea Locke	
Chris Van Rooyen	Eskom-EWT
Bob Hartman	Kaddas Enterprises Inc.
Debra Crowe	CH2MHill Inc.
Tom Ring	Montana Department of Environmental Quality
Tom Telfer	Hawaii Department of Forestry and Wildlife
Tony Jacobson	U.S. Army Corps of Engineers
Sussy de la Zerda	University of Columbia, SA

C
CAUSEWAY DEAD-BIRD SEARCH PROTOCOL

Searchable Areas and Transects

Dead bird searches are conducted from approximately 15 April to 31 October annually. Search area extends along the causeway between structures 12/5 and 14/6 and across the causeway from the top of the riprap on the west bank (approximately 110 ft [33.5 m] from the western-most conductor) to nearly the shore of Lake Audubon on the east for Spans 2–11, or to specified distances east of the transmission line for Spans 1, 12, and 13.

The paved surface of Highway 83 (“highway transect”) is searched from a vehicle while slowly driving on highway shoulders. Four additional strip transects extending along all or most of the causeway are searched on foot (Figure 5-5). One transect includes the rail line and ditch between the highway and rail line (“railway-ditch transect”). It is necessary to mow the ditch frequently enough to ensure a high probability of finding birds. Another transect consists of the narrow strip of bare earth and sparse vegetation between the guardrail and east riprap (“dirt-strip transect”). This area cannot be searched safely or efficiently while driving on the highway or while searching the riprap. Highway, railway-ditch, and dirt-strip transects are continuous between structures 12/5 and 14/6. Two transects lie within the riprap under the transmission line (east of the highway guardrail) and extend continuously from the south end of Span 2 to the north end of Span 11 (Figure 5-5). Search points have been established on lines running through the riprap, parallel to the highway and shoreline, approximately 12 ft (3.7 m) below the top of the riprap (“upper riprap transect”) and a similar distance above the waterline (“lower riprap transect”). Points are marked with paint approximately 25 ft (7.6 m) apart along each line.

Spans 1, 12, and 13 need to be monitored because they occur in potentially heavily used flight corridors along lake shorelines at south and north ends of the causeway. However, each of these spans is unique and differs importantly from Spans 2–11, so modified search procedures are required. However, railway-ditch, highway, and dirt-strip transects are consistent in Spans 1–13 and each is searched as a continuous transect.

Searchable area and search patterns in Span 1 differ from the consistent pattern of Spans 2–11 because riprap width varies, three power lines converge into one right of way at structure 12/6 (not all lines are parallel to the highway), and greater area of dry land exists at the south end of Span 1. The search area east of the highway includes a gradually tapering section of riprap that is searched as above but the south half of this span has only a single line of point transects, while the north half retains the pattern of two parallel lines of point transects. Much of the search area for this span consists of meadow and it is necessary to manage annual vegetation growth by mowing or grazing to maximize visibility of dead birds. Searchable area of the meadow extends (approximately eastward) 164 ft (50 m) from the outermost conductor (Figure 5-6). In 2001, meadow transect lines (orientated transverse to the transmission line direction) spaced at approximately 33 ft (10 m) were searched by one person. The searcher walked each line and focused attention on an area 33-ft (10-m) wide, centered on the line of travel. In 2002, two searchers walked in tandem, spaced at approximately 16 ft (5 m), each focusing search effort on a 16-ft (5-m) wide strip (essentially doubling the number of transect lines shown in Figure 5-6). Span 13 also has extensive areas of dry land south of the power line and similar meadow search methods were used there (Figure 5-8). In future years, meadow transect lines will be spaced at 16 ft (5 m).

Riprap adjacent to the dirt-strip transect on the south end of Span 12 transitions into a sloped vegetated bank and a graveled road north of the substation (Figure 5-7 and Figure 5-8). The gravel road is walked from the substation parking lot northward to structure 14/6, and the road and sloped bank are searched as a single transect. Additional transects in Span 12 include lower and upper riprap transects around the substation, a substation perimeter transect, and a single transect line in riprap east of the gravel road from the substation to slightly north of structure 14/5. These riprap transects are also searched at points spaced approximately 25 ft (7.6 m) apart. The substation is searchable area but must be accessed by Western Area Power Administration or Bureau of Reclamation personnel to recover dead birds. We consider the pond in Span 13 to be searchable because birds can be recovered along the edges and because the pond was dry in 2002.

Schedule and Pattern of Searches

In general, searchers work three days on and one day off to minimize time between searches at individual transects. In 2001, highway transects (causeway and potholes) were searched six times/four days and each walking transect was searched one time/four days, weather permitting. Highway searches at the causeway and pothole transects were conducted morning and evening each search day. We alternated transect order and travel direction in midday searches to minimize potential for bias (see “Schedule of Midday Searches, 2001” below. Actual schedule and pattern of transect searches was documented (see “Transect Search Log, 2001” below). We modified the midday search schedule and log sheets in 2002 because two persons conducted searches (see “Schedule of Midday Searches, 2002” and “Transect Search Log, 2002” below).

Schedule of Midday Searches, 2001

Work cycle 1,	Day 1	Lower-riprap Transect (12/6 to 14/4), south to north
		Railway-ditch Transect (12/6 to 14/6), north to south
	Day 2	Upper-riprap Transect (12/6 to 14/4), north to south
		Dirt-strip Transect (12/5 to 14/6), south to north
	Day 3	South-end Transects (12/5 to 12/6), riprap then meadow
		North-end Transects (14/4 to 14/6), riprap-meadow-road-sub perimeter
	Day 4	Off
Work cycle 2,	Day 1	Railway-ditch Transect (12/6 to 14/6), north to south
		Lower-riprap Transect (12/6 to 14/4), south to north
	Day 2	Dirt-strip Transect (12/5 to 14/6), south to north
		Upper-riprap Transect (12/6 to 14/4), north to south
	Day 3	North-end Transects (14/4 to 14/6), riprap-meadow-road-sub perimeter
		South-end Transects (12/5 to 12/6), riprap then meadow
	Day 4	Off
Work cycle 3,	Day 1	Lower-riprap Transect (12/6 to 14/4), north to south
		Railway-ditch Transect (12/6 to 14/6), south to north
	Day 2	Upper- riprap Transect (12/6 to 14/4), south to north
		Dirt-strip Transect (12/5 to 14/6), north to south
	Day 3	South-end Transects (12/5 to 12/6), meadow then riprap
		North-end Transects (14/4 to 14/6), sub perimeter-road-meadow-riprap
	Day 4	Off
Work cycle 4,	Day 1	Railway-ditch Transect (12/6 to 14/6), south to north
		Lower-riprap Transect (12/6 to 14/4), north to south
	Day 2	Dirt-strip Transect (12/5 to 14/6), north to south
		Upper-riprap Transect (12/6 to 14/4), south to north
	Day 3	North-end Transects (14/4 to 14/6), sub perimeter-road-meadow-riprap
		South-end Transects (12/5 to 12/6), meadow then riprap
	Day 4	Off

Work cycles 5-8, 9-12, ….. repeat above.

Transect Search Log, 2001

Day 1

Date (m/d/y) ____/____/____ Observer ____________________

Morning Highway Transect Search: Start Time (24 h) ________ End Time (24 h) ________

Midday Search:

First Transect:	☐ South End Span (12/5 – 12/6)	☐ North End Spans (14/4 – 14/6)
Order:	☐ riprap-meadow ☐ meadow-riprap	☐ subp-rd-m-riprap ☐ riprap-m-rd-subp
Time (24 hr):	Start End	Start End
2nd Transect:	☐ South End Span (12/5 – 12/6)	☐ North End Spans (14/4 – 14/6)
Order:	☐ riprap-meadow ☐ meadow-riprap	☐ subp-rd-m-riprap ☐ riprap-m-rd-subp
Time (24 hr):	Start End	Start End

Evening Highway Transect Search: Start Time (24 h) ________ End Time (24 h) ________

Day 2

Date (m/d/y) ____/____/____ Observer ____________________

Morning Highway Transect Search: Start Time (24 h) ________ End Time (24 h) ________

Midday Search:

First Transect: ☐ Dirt Strip ☐ Upper Riprap

Direction: ☐ N ☐ S Start Time (24 h) ________ End Time (24 h) ________

Second Transect: ☐ Dirt Strip ☐ Upper Riprap

Direction ☐N ☐ S Start Time (24 h) ________ End Time (24 h) ________

Evening Highway Transect Search: Start Time (24 h) ________ End Time (24 h) ________

Day 3

Date (m/d/y) ____/____/____ Observer ____________________

Morning Highway Transect Search: Start Time (24 h) ________ End Time (24 h) ________

Midday Search:

First Transect: ☐ Railway-Ditch ☐ Lower Riprap

Direction: ☐ N ☐ S Start Time (24 h) ________ End Time (24 h) ________

Second Transect: ☐ Railway-Ditch ☐ Lower Riprap

Direction ☐N ☐ S Start Time (24 h) ________ End Time (24 h) ________

Evening Highway Transect Search: Start Time (24 h) ________ End Time (24 h) ________

Schedule of Midday Searches, 2002

Work cycle 1, Day 1 **Tech A**:
Lower-riprap Transect (12/6 to 14/4), south to north, then
Railway-ditch Transect (12/5 to 14/6), north to south
Tech B:
Upper-riprap Transect (12/6 to 14/4), south to north, then
Dirt-strip Transect (12/5 to 14/6), north to south

Day 2 South-end Transects (12/5 to 12/6), riprap then meadow, then
North-end Transects (14/4 to 14/6), riprap-meadow-road-sub perimeter
Tech A: Upper riprap and on orange transect lines in meadow
Tech B: Lower riprap and on green transect lines in meadow

Day 3 **Tech A**:
Upper-riprap Transect (12/6 to 14/4), south to north, then
Dirt-strip Transect (12/5 to 14/6), north to south
Tech B:
Lower-riprap Transect (12/6 to 14/4), south to north, then
Railway-ditch Transect (12/5 to 14/6), north to south

Day 4 South-end Transects (12/5 to 12/6), riprap then meadow, then
North-end Transects (14/4 to 14/6), riprap-meadow-road-sub perimeter
Tech A: Lower riprap and on green transect lines in meadow
Tech B: Upper riprap and on orange transect lines in meadow

Day 5 **Tech A**:
Lower-riprap Transect (12/6 to 14/4), north to south, then
Railway-ditch Transect (12/5 to 14/6), south to north
Tech B:
Upper-riprap Transect (12/6 to 14/4), north to south, then
Dirt-strip Transect (12/5 to 14/6), south to north

Day 6 North-end Transects (14/4 to 14/6), riprap-meadow-road-sub perimeter
South-end Transects (12/5 to 12/6), riprap then meadow, then
Tech A: Upper riprap and on orange transect lines in meadow
Tech B: Lower riprap and on green transect lines in meadow

Day 7 **Tech A**:
Upper-riprap Transect (12/6 to 14/4), north to south, then
Dirt-strip Transect (12/5 to 14/6), south to north
Tech B:
Lower-riprap Transect (12/6 to 14/4), north to south, then
Railway-ditch Transect (12/5 to 14/6), south to north

Day 8 North-end Transects (14/4 to 14/6), riprap-meadow-road-sub perimeter
South-end Transects (12/5 to 12/6), riprap then meadow, then
Tech A: Lower riprap and on green transect lines in meadow
Tech B: Upper riprap and on orange transect lines in meadow

Work cycles 2, 3, 4, ….. repeat above, continuing a pattern of 3 days on and 1 day off.

Transect Search Log, 2002

Date (m/d/y) ____/____/____ Work Cycle __________ Day or Search Pattern in Cycle __________

Morning Highway Transect Observer(s): ____________________

Morning Hwy Transect Causeway: Start Time (24 h) __________ End Time (24 h) __________

Morning Hwy Transect Potholes: Start Time (24 h) __________ End Time (24 h) __________

Midday Search:

Observer:

Transect	Direction/Order	Start Time (24 h)	End Time (24 h)

Observer:

Transect	Direction/Order	Start Time (24 h)	End Time (24 h)

Evening Highway Transect Observer(s): ____________________

Evening Hwy Transect Causeway: Start Time (24 h) __________ End Time (24 h) __________

Evening Hwy Transect Potholes: Start Time (24 h) __________ End Time (24 h) __________

Date (m/d/y) ____/____/____ Work Cycle __________ Day or Search Pattern in Cycle __________

Morning Highway Transect Observer(s): ____________________

Morning Hwy Transect Causeway: Start Time (24 h) __________ End Time (24 h) __________

Morning Hwy Transect Potholes: Start Time (24 h) __________ End Time (24 h) __________

Midday Search:

Observer:

Transect	Direction/Order	Start Time (24 h)	End Time (24 h)

Observer:

Transect	Direction/Order	Start Time (24 h)	End Time (24 h)

Evening Highway Transect Observer(s): ____________________

Evening Hwy Transect Causeway: Start Time (24 h) __________ End Time (24 h) __________

Evening Hwy Transect Potholes: Start Time (24 h) __________ End Time (24 h) __________

Search Protocol and Data Collection

Paved surfaces of Highway 83 at the causeway (highway transect) and pothole transects at the reference site are searched from a vehicle twice daily: at first light in morning and just before dark in evening. These transects are searched while slowly driving a round-trip circuit on each of the highway shoulders. Before conducting the morning search, a highway department approved sign alerting traffic that work crews are present on the highway is placed on the shoulder at the starting end of the causeway. A similar sign is placed at the other end of the causeway before conducting the return portion of the circuit.

Search protocol in riprap transects involves concentrated search effort while at points only, because looking for birds while walking in the riprap compromises safety of searchers. While in transit between points, concentration is directed toward safely traversing the rocks to the next search point. At each search point, the observer slowly rotates 360° and searches within a radius of about 25 ft (7.6 m). This protocol provides overlapping search patterns to increase bird detection probability by looking at the same areas from different directions.

Railway-ditch, dirt-strip, meadow, and substation perimeter and gravel road transects are searched by slowly walking and scanning transect cross sections.

The following information is collected for each dead bird and feather spot (partial carcasses) found during searches (see sample data sheet below entitled “Audubon Causeway Bird Carcass Recovery Data”). General location referenced by span and transect name, and specific location consisting of distance from south tower of span and transverse distance from highway guardrail are recorded. Distance between towers is marked on wood stakes at 50-ft (15.2-m) intervals beginning at the south tower of each span. These stakes provide a coordinate system for the longitudinal direction of the power line, enabling location of dead birds to the nearest 25 ft (7.6 m) from the south tower of each span. Transverse coordinates of dead birds are obtained by extending a tape measure from the guardrail, which serves as the reference or zero line for transverse coordinates. Date, time, species, sex, age class, probable cause of death, and comments are also recorded. One or more photographs are required for all carcasses and each photo includes a 4 in. x 6 in. (102 mm x 152 mm) card with specimen number clearly visible. All carcasses are tagged for identity, sealed in plastic bags, and removed at the time of survey. Dead birds observed in Lake Audubon are recovered if possible (using an extendable catch-pole), documented as above, and removed. If dead birds cannot be recovered all possible data are entered on a carcass recovery form but “not recoverable” is recorded in place of specimen number.

Dead birds marked for bias estimation (beak, toenail, and wings clipped, and legs tape wrapped) are recorded on a bird carcass recovery data form, clearly indicating the bird was a test specimen and not a newly dead bird. Specimen number, all location information, and condition information specifying whether specimen is still acceptable for replanting are provided on the form. Search and removal bias specimens are removed like newly dead birds.

Other dead animals and garbage that might attract scavengers (particularly food and food wrappers) are removed from all transects for disposal at the Refuge. Objectives are to minimize scavenging of bird carcasses in general by reducing overall level of scavenger attractants, and to reduce potential for vehicle collision with avian scavengers attracted by food items located on or near the highway. All foreign objects found on highway, ditch, and dirt strip transects are removed to eliminate distraction when conducting driving searches for birds.

Precautions are taken while handling animal carcasses to ensure health and safety. A fresh pair of disposable rubber gloves are used for each carcass and disposed of after sealing the carcass in a plastic bag. Used rubber gloves are sealed in a Ziploc plastic bag. Disinfectant wipes are carried for hygiene.

We contact the McLean County Sheriff's office at the beginning of each field season to notify them of work schedules, personnel and vehicle information, and emergency contacts. When the project vehicle is parked on the causeway to recover carcasses or other objects, it is parked on highway shoulders so as not to obstruct traffic, orange safety cones are deployed behind the vehicle toward oncoming traffic, and emergency flashers are activated (satisfies North Dakota Department of Transportation requirements for contractors). The biologist must wear an approved safety vest at all times while working on the causeway, including time spent searching all transects.

Considerable time is spent on the causeway conducting dead bird searches and potential exists for opportunistic observations of birds colliding with wires. Separate data sheets are provided to document strike information including observer, date, time, species, sex, age, flight direction, weather conditions, span and wire struck, and outcome of strike (see sample data sheet below entitled "Bird Strikes on Transmission Line Wires Observed at Audubon Causeway").

Audubon Causeway Bird Carcass Recovery Data

Date (m/d/y): _____ / _____ / _____ Time (24 h): __________

Observer: ______________________________

Describe bands (colors, numbers): ____________________

Specimen number: _______ Photo numbers: __________ Species: __________

Sex: ☐ Male ☐ Female ☐ Unknown

Age Class: ☐ Adult ☐ Juvenile ☐ Unknown

Description (if species, sex, or age unknown; coloration, size, beak, feet): __________

Condition (alive/dead, broken bones, lacerations, abrasions, blood, discolorations, gunshot wounds, decomposition, damage from scavenging): __________

Cause of Death: ____________________

Location of Carcass:

Span identification (both towers): S. Tower No. ________ N. Tower No. ________

Longitudinal distance from south tower of span (nearest 25 ft): ________ ft

Transverse distance from guardrail (snug tape, nearest 1 ft): ________ ft

General location within spans **12/6 to 14/4** (check one):

☐ Railway-Ditch Transect ☐ Highway Transect ☐ Dirt Strip ☐ Upper Riprap Transect
☐ Lower Riprap Transect ☐ Lower 3 ft Riprap ☐ Lake Audubon

General location within span **12/5 – 12/6** (check one):

By Lake: ☐ Railway-Ditch Transect ☐ Highway Transect ☐ Dirt Strip ☐ Upper Riprap
☐ Lower Riprap Transect ☐ Lower 3 ft Riprap ☐ Lake Audubon
☐ Meadow

South of Lake: ☐ Railway-Ditch Transect ☐ Highway Transect ☐ Dirt Strip
☐ Riprap ☐ Meadow

General location within span **14/4 to 14/4.5** (check one):

☐ Railway-Ditch Transect ☐ Highway Transect ☐ Dirt Strip ☐ E. Bank-Parking-Road-Sub
☐ Upper Riprap Transect ☐ Lower Riprap Transect ☐ Lower 3 ft Riprap ☐ Lake Audubon

General location within span **14/4.5 to 14/5** (check one):

☐ Railway-Ditch Transect ☐ Highway Transect ☐ Dirt Strip ☐ Upper Riprap ☐ GrvRd
☐ Lower Riprap ☐ Lower 3 ft Riprap-Beach ☐ Lake Audubon ☐ Trees

General location within span **14/5 to 14/6** (check one):

☐ Railway-Ditch Transect ☐ Highway Transect ☐ Dirt Strip ☐ E. Bank
☐ Gravel Road ☐ Trees ☐ Meadow ☐ Pond

Bird Strikes on Transmission Line Wires Observed at Audubon Causeway

Date (m/d/y): ______/______/______ Time (24 h): __________

Observer: ______________________________

Species: ______________________________

Sex: ☐ Male ☐ Female ☐ Unknown

Age Class: ☐ Adult ☐ Juvenile ☐ Unknown

Description (if species, sex, or age unknown): ______________________________

____

____

Flight direction before strike: ☐ N ☐ NE ☐ E ☐ SE ☐ S ☐ SW ☐ W ☐ NW

Weather conditions: ☐ Cloudy ☐ Partly Cloudy ☐ Clear ☐ Fog ☐ Light Rain

☐ Moderate Rain ☐ Heavy Rain ☐ Light Snow ☐ Moderate Snow ☐ Heavy snow

☐ Calm ☐ Light Wind ☐ Moderate Wind ☐ Strong Wind

Wind Direction: ☐ N ☐ NE ☐ E ☐ SE ☐ S ☐ SW ☐ W ☐ NW

Span identification (list both tower numbers): S. Tower No. __________ N. Tower No. __________

Longitudinal distance (strike) from south tower of span (nearest 50 ft): __________ ft

Wire struck: ☐ 1E ☐ 1M ☐ 1W ☐ 2E ☐ 2W ☐ 3E ☐ 3W

☐ 4E ☐ 4W ☐ 5E (top, ground wire) ☐ 5W (top, ground wire) ☐ Unsure

Result of strike: ☐ Death ☐ Injury (bird on ground/water, not seen to fly away)

☐ Injury (bird on ground/water, later seen flying away) ☐ Bird continued flight (impaired)

☐ Bird continued flight (unimpaired)

Location where bird fell: ☐ Ground ☐ Water (describe): ______________________________

Span identification (both towers): S. Tower No. __________ N. Tower No. __________

Longitudinal distance from south tower of span (nearest 25 ft): __________ ft

Transverse distance from guardrail (snug tape, nearest 1 ft): __________ ft

Comments, including bird movements following landing on ground/water:

____

____

____

____

D
REFERENCE GUIDE FOR CLASSIFYING CAUSE OF DEATH FROM SIMPLE NECROPSY

Power Line Collisions:

Any 1 or combine any 2 of the following with or without minor blood build up and/or bruising, and **not associated with crushed body cavity (see section of vehicle collision injuries), broken spine, hips, legs, or both wings**.

- Broken collarbone(s)
- Broken neck
- Broken wing (1 only)
- Broken breastbone

Also the following:

- Indentations on breast suggestive of striking a cylindrical object like a wire, with or without above traumas, but not associated with crushed body cavity (see section of vehicle collision injuries), broken spine, hips, legs, or both wings
- Minor blood build up and/or bruising on neck and breast with no broken bones

Vehicle Collision:

- Body cavity crushed (always conclude vehicle collision if present)

Any combination of

- Broken spine
- Broken hips
- Broken tail
- Broken legs

Any combination of three or more

- Broken Collarbone(s)
- Broken Neck
- Broken Wing
- Broken Breastbone

Also, the presence of extensive blood and bruising is typical but not sufficient for vehicle collision classification.

Other:

- Botulism
- Hunter Wounded, presence of entrance and/or exit wounds
- Unknown, no internal or external damage

E
POTHOLE TRANSECT SEARCH PROTOCOL

Seven transects (identified A–G,Table 5-2) have been established near pothole and wetland areas between the intersection of N. D. Hwy 37 and U.S. Hwy 83 (Garrison turnoff or "six mile corner"). Transects are delineated by wooden stakes driven close to existing road-sign or reflector posts to minimize conflicts with mowing. They are marked by transect letter and N or S, signifying north end and south end of transect. All but transects C and E have been divided into subtransects to facilitate collection of bird overflight data (Appendix F).

Searchable area of transects consists of the **paved** surfaces of both northbound and southbound lanes. Both northbound and southbound lanes are searched but data are recorded to allow for segregation of data by travel lanes to assess influences of the low powerline west of the highway.

Search Methods

Pothole transects are intensively searched from a vehicle driven slowly along pothole transect highway shoulders to ensure no birds are missed on paved surfaces within transect boundaries. A round-trip circuit of pothole transects is conducted in morning and evening in conjunction with causeway highway searches. Identical search methods are used at both areas to enable comparisons between areas. All plantable birds found anywhere along US Highway 83 between "six mile corner" and the northern limit of the pothole transects are collected for necropsy and planting. Birds found outside of established transects are considered incidental and intensive search of non-transect areas is not required.

Birds found within pothole transects are identified and recorded by year, subtransect, and sequential specimen number, for example 02-A1-001, 02-A1-002, 02-A1-003,… for birds found in subtransect A1. Standard causeway data sheets are used to record data for birds found dead at pothole transects, but less specific location data are recorded. However, searchers are required to **indicate northbound or southbound lanes and note all birds found on vegetated shoulders or median ("off highway"), rather than paved surfaces ("highway")**. On data sheet, for "General Location Transverse to Span" put "highway" or "off highway", and for "off highway" birds indicate east (E) or west (W) side of northbound (NB) or southbound (SB) travel lanes.

Incidental plantable birds found outside of pothole transects are identified as 02-X001, 02-X002, 02-X003,…, and approximate locations are noted. For example, "Between ND 37 and transect A, northbound lanes." Again, it is important to identify northbound versus southbound lanes. In storage, incidental, pothole, and causeway specimens are segregated to facilitate planting only incidental or pothole birds at pothole transects and causeway birds at causeway transects.

Flattened, dismembered, or deteriorated birds found on paved highway surfaces or vegetated shoulders at pothole transects, or along the highway within 50 ft (15.2 m) of transects are thrown into ditches at least 50 ft (15.2 m) from transects to minimize probability of scavengers moving birds into transects. Note that all birds found within pothole transects will be assigned an ID and recorded, but only "plantable" birds will be collected.

We collect and necropsy birds found on or off the highway, but only counts of dead birds found on paved surfaces within established pothole transects are comparable with causeway highway transect numbers. We assume birds found on or off highway at pothole transects are killed by vehicle collision, but will examine necropsy results for evidence of wirestrike fatalities (e.g., by testing for greater numbers of "wirestrike" classifications for birds found closer to wires).

F
BIRD OVERFLIGHT OBSERVATIONS AND VEHICLE COUNTS

Observations are conducted in late afternoon before evening highway searches at both causeway and pothole areas as often as time will permit. When possible, observations are made immediately following morning searches on days when regular causeway searches of riprap and meadows are not scheduled (i.e., crew leader is doing both morning and evening highway searches). Observations are taken on one causeway span/day and one pothole transect or subtransect/day (Table F-1). Order between areas is alternated daily, i.e. causeway first one day and pothole first next day. We rotate sequentially through causeway spans and pothole transect segments from one day to the next.

For example, first day search pothole highway transects, do bird and vehicle counts at pothole transect A1, search causeway highway transects, do bird and vehicle counts at causeway Span 1. Second day search causeway highway transects, do bird and vehicle counts at causeway Span 2, search pothole highway transects, do bird and vehicle counts at pothole transect A2. Third day search pothole highway transects, do bird and vehicle counts at pothole transect B1, search causeway highway transects, do bird and vehicle counts at causeway Span 3. And so on…

Observation periods at each site (causeway and pothole) consist of 6, 10-min blocks, alternating between counting traffic (separately by northbound and southbound lanes) and birds flying across at least the northbound or southbound lanes of the highway. A digital watch with a countdown function is used to time each 10-min period. Observations are taken from the northbound lanes at pothole transects and southbound lanes at causeway spans because shoulders are wider there. Record species-specific numbers of birds in each group if they are within the highway segment being observed and if they are within about one semi-trailer height of the highway surface (for our purposes, 15 ft [4.6 m]). Note this approximate height as trucks pass by in relation to nearby power-line towers or poles, and use these visual references during observation periods. If only part of a group is within 15 ft (4.6 m) of highway surface, count only those birds. In areas with high levels of bird flight activity, a tape recorder is used to record low-flying groups by number-within-group and species. Each group, even if group size is one bird, is recorded individually on data sheets. Subjective judgment is required in determining what constitutes a group of birds, and whether group is low or high, and within transect. Strive for consistency over time and between areas.

Identify birds by species if possible, but minimally, classify bird according to groups shown in Table F-2. Use abbreviations on data sheets, but use group names or species names in data file. Sometimes there is an identification hierarchy between the general groups in Table F-2 and the species level (Table F-3), for example:

Passerine

- Blackbird
  - Blackbird, red-winged
  - Blackbird, yellow-headed
  - Blackbird, Brewer's
  - Grackle
  - Cowbird
  - Etc…..

Intermediate groupings can be designated and used because it is not always possible to identify species, but it is possible to do better than the minimum level of classification. For example, you may be able to identify black terns, but could not always tell the difference between common and Forester's terns so used the designation "CF Tern". Also, because most blackbirds are more readily identifiable at a distance than other passerines, "Passerine" typically has meant all passerines other than black birds.

Use the bird flight observation data sheet to record traffic volumes, also. For species put "car" (typical passenger vehicles, sedans, SUVs, light-duty trucks) or "semi" (all large vehicles traveling at normal highway speeds, such as buses, large delivery trucks and semis). Ignore slow moving agricultural equipment, etc. Make separate counts for southbound and northbound lanes. For each 10-min vehicle count period there will be four numbers recorded under species group on the bird flight observations sheet: cars northbound (Car NB), Car SB, Semi NB, Semi SB. Again, for large traffic volumes the tape recorder is used.

Table F-1
Pothole Transect Sub-Transect Locations

Transect	Sub-Transect[1]	Stake		Length (ft)	
		South	North	Transect	Sub-Transect
A	A1	AS	AC	2255	1063
	A2	AC	AN		1192
B	B1	BS	BC1	3153	1144
	B2	BC1	BC2		799
	B3	BC2	BN		1210
C	Na	CS	CN	486	na
D	D1	DS	DC	1988	951
	D2	DC	DN		1037
E	Na	ES	EN	1060	na
F	F1	FS	None	1590	≈1/2F
	F2	None	FN		≈1/2F
G	G1	GS	None	1447	≈1/2G
	G2	None	GN		≈1/2G

[1] Sub-transect end stakes for A, B, and D are either original transect end stakes or intermediate reflector posts marked with number in black marker ink and orange flagging. No intermediate stakes for F and G; park in approximate middle and make observations from there. Record dead bird locations by sub-transect.

Table F-2
Minimum Classification Level for Birds Flying Over Highway

Abbreviation	Group Name
CT	Coot
CR	Cormorant
DO	Dove
DU	Duck
GO	Goose
GR	Grebe
GU	Gull
H	Heron
PA	Passerine
PE	Pelican
PH	Pheasant
R	Raptor
S	Shorebird
T	Tern

Table F-3
Examples of Abbreviations, Species, and Species Groups - Others are Possible

Abbrev.	Species or Species Group	Abbrev.	Species or Species Group
AV	Avocet	NB	No Birds, if none seen/10 min obs pd
BB	Blackbird	PT	Pintail
RWB	Blackbird, Red-winged	PP	Plover, Piping
YBB	Blackbird, Yellow-headed	SPP	Sandpiper
CB	Cowbird	USPP	Sandpiper, Upland
Crow	Crow	SP	Sparrow
MD	Dove, Mourning	SW	Swallow
RND	Duck, Ringneck	BSW	Swallow, Bank
GD	Gadwall	CSW	Swallow, Cliff
CanG	Goose, Canada	TL	Teal
GRK	Grackle	BTL	Teal, Blue-winged
CalG	Gull, California	BT	Tern, Black
FrG	Gull, Franklin's	CFT	Tern, CF (Common or Forester's)
RbG	Gull, Ringbilled	COT	Tern, Common
SH	Hawk, Swainson's	UNK	Unknown
GBH	Heron, Great Blue	WB	Warbler
KD	Killdeer	**Don't Use**	Waterfowl - Use Duck or Goose
KB	Kingbird	WW	Waxwing
EKB	Kingbird, Eastern	BWW	Waxwing, Bohemian
WKB	Kingbird, Western	CWW	Waxwing, Cedar
MP	Magpie	WG	Wigeon
ML	Mallard	WL	Willet

Highway Overflight Observations (Birds Crossing ≥2 Lanes within Approximately 15 ft of Highway Surface)

Date (m/d/y): / /		Causeway Span or Pothole Transect:		Observer:	
Time (24h) Start | End	Group Size or Vehicle Count	Species or Species Group Or Vehicle Type	Time (24h) Start | End	Group Size or Vehicle Count	Species or Species Group Or Vehicle Type